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HP-25 Programmable Pocket Calculator Applied to Air Pollution Measurement Studies: Stationary Sources

Southern Research Inst, Birmingham, Ala

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Industrial Environmental Research
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Research Triangle Park, North Carolina 27711

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HP-25 PROGRAMMABLE POCKET CALCULATOR APPLIED TO AIR POLLUTION MEASUREMENT STUDIES: STATIONARY SOURCES

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16. ABSTRACT The report should be useful to persons concerned with Air Pollution Measurement Studies of Stationary Industrial Sources. It gives detailed descriptions of 22 separate programs, written specifically for the Hewlett Packard Model HP-25 manually programmable pocket calculator. Each program includes a general description, formulas used in the problem solution, program listings, user instructions, and numerical examples. Areas covered include: Methods 1 through 8 of the EPA Test Codes (Federal Register, December 23, 1971), calibrating a flame photometric detector by the permeation tube technique, determining channel concentrations for a droplet measuring device, resistivity and electric field strength measurements, determining stack velocity, nozzle diameter, and isokinetic delta H for a high-volume stack sampler, and several cascade impactor programs. Cascade impactor programs include: determining impactor stage cut points, calculating the square root of the Stokes number for round jet and for rectangular slot geometries, nozzle selection and determining delta H for isokinetic sampling, determining sampling time required to collect 50 mg total sample, determining impactor flow rate, sample volume, and mass loading, and calculating cumulative concentration curves and their differentials.

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by

James W. Ragland, Kenneth M. Cushing,
Joseph D. McCain, and Wallace B. Smith

Southern Research Institute
2000 Ninth Avenue, South
Birmingham, Alabama 35205

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Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
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ABSTRACT

This report is intended to provide a useful tool to persons concerned with Air Pollution Measurement Studies of Stationary Industrial Sources. Detailed descriptions are given for twenty-two separate programs that have been written specifically for the Hewlett Packard Model HP-25 manually programmable pocket calculator. Each program includes a general description, formulas used in the problem solution, program listings, user instructions, and numerical examples. Areas covered include the following: Methods 1 through 8 of the EPA Test Codes (Federal Register, December 23, 1971), calibration of a flame photometric detector by the permeation tube technique, determination of channel concentrations for a droplet measuring device, resistivity and electric field strength measurements, determination of stack velocity, nozzle diameter, and isokinetic delta H for a high volume stack sampler, and several programs for cascade impactors. Those for cascade impactors include: determination of impactor stage cut points, calculation of the square root of the Stokes number for round jet and for rectangular slot geometries, nozzle selection and determination of delta H for isokinetic sampling, determination of sampling time required to collect 50 mg total sample, determination of impactor flow rate, sample volume, and mass loading, and calculation of cumulative concentration curves and their differentials.

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SECTION I
INTRODUCTION

GENERAL

The programs in this manual have been selected from the areas of Compliance Testing, Cascade Impactor Operation, Mass Train Operation, Resistivity Measurements, etc., and written for the Hewlett Packard Model HP-25 manually programmable pocket calculator. A manual giving many of these same programs in a modified form for use with a Hewlett Packard Model HP-65 card programmable pocket calculator is also available. Each program herein includes a general description, formulas used in the problem solution, program listings, user instructions, and numerical examples.

At the time of this writing the December 23, 1971 Federal Register (Volume 36, No. 247, Part II) "Standards of Performance for New Stationary Sources; Appendix - Test Methods" sets forth the official EPA test methods. Consequently, Section II of this text (programs APol-01 through APol-08) has been based on the December 1971 document except as noted below.

A proposed amendment to the test methods had been set forth in the June 8, 1976 Federal Register (Volume 41, No. 111) and minor changes to the programs contained in this document may be required when the modified procedures are adopted.

In contrast to the equations set forth in the December 23, 1971 Federal Register, the equations in this text use 68°F (20.0°C) as Standard Temperature, rather than 70°F (21.1°C).

The difference in absolute temperature, at constant pressure, between 20.0°C and 21.1°C introduces only a very slight change in the sample volume. The conversion factors are:

$$V_{(21.1^\circ C)} = 1.0038\,V_{(20.0^\circ C)}$$

and

$$V_{(20.0^\circ C)} = 0.9962\,V_{(21.1^\circ C)}.$$

For the convenience of the user, most input data requirements call for English units. The output for such cases is also in English units; however, the program steps provide for direct conversion to metric units for reporting purposes. The terms "standard conditions" and "normal conditions" are used interchangeably and refer to 68°F (20.0°C) temperature and 29.92 inches Hg (760 Torr) pressure. Some temperature values are entered in °F (or °C) rather than °R (or °K) although the formula being worked may specify "absolute" temperature. Conversion to "absolute" units is accomplished internally.

FORMAT OF USER INSTRUCTIONS

The following is an example of a set of user instructions.

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Store variables		H	↑		
			B	↑		
			d	R/S		4
4	Compute E	01	(H)	STO	2	
			(B)	STO	7	
			(d)	STO	1	
				R/S		E
5	Compute $(\sqrt{\Delta P})_{avg}$, for $(\Delta P_i, R_i)$		(E)	STO	4	
	a. Sum data sets	12	ΔP_i	↑		
	(Do i = 1 → N)		R_i	R/S		
	b. Compute $(\sqrt{\Delta P})_{avg}$	28		GTO	28	
				R/S		$(\sqrt{\Delta P})_{avg}$
6	Compute γ		$((\sqrt{\Delta P})_{avg})$	STO	5	
			(Σ)	STO	4	
			N	R/S		γ
7	(For different γ, store new values					
	as required then proceed to					
	Step 5)					

To follow the instructions, start with line 1 and read from left to right, performing the indicated operations as you proceed.

Steps are read in sequential order except where the INSTRUCTIONS column directs otherwise. Repeated processes used in most cases for a long string of input/output data are outlined with a bold border together with a "Do" instruction. For example,

$$\text{Do } i = 1 \rightarrow N$$

means to execute the loop N times. On the first pass, the dummy variable i takes on the value 1; on the second pass i takes on the value 2, etc.

Some instructions are self contained and can be carried out by simply reading the INSTRUCTIONS column alone. But most instructions depend on the information supplied by the DATA and/or KEYS columns. In Step 3 of the example "Store variables" appears in the INSTRUCTIONS section and H, B, and d appear in the DATA section. They keystroke symbols $\boxed{\uparrow}$ and $\boxed{\text{R/S}}$ appear in the KEYS section. This means that to "Store variables", one must load the appropriate value for the variable H and press $\boxed{\uparrow}$, load the appropriate value for the variable B and press $\boxed{\uparrow}$, then load the appropriate value for the variable d and press $\boxed{\text{R/S}}$. The number "4.00" will be displayed when this sequence of program instructions has been completed.

The LINE NO. column is included for the convenience of the user. Each time manual branching is required, an entry in the KEYS column of the program instructions informs the operator of this requirement (e.g., Step 5b: GTO 28). It should be noted that the GTO command requires a two digit address code (i.e., 01 not 1). The command R/S restarts program execution from wherever the program pointer is positioned.

The DATA column specifies the input data to be supplied. Symbols are defined in the test and correct units are shown in the Example section.

A special notational format has been adopted which allows the operator to modify the sequence of operating instructions. The use of parentheses around a variable (as shown in the DATA column for line 4) indicates that when operating instructions are followed in the indicated sequence the appropriate value will have already been loaded in the correct storage register. Operations shown in parentheses are only used to change the magnitude of variables already stored by previous entry or calculation. **OPERATIONS SHOWN IN PARENTHESES ARE OMITTED FOR NORMAL OPERATION.**

For the convenience of the reader, Appendix A gives a brief review of operating instructions for the HP-25. For more extensive instruction the reader is referred to the HP-25 owner's handbook.

SECTION II

METHOD 1

SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

TRAVERSE POINTS-CIRCULAR DUCT

For a circular duct, the distance from flange to traverse point (t_j as shown below) is given by:

$$t_j = \left(d + \frac{D}{2}\right) \pm \alpha_i \qquad (1\text{-}1)$$

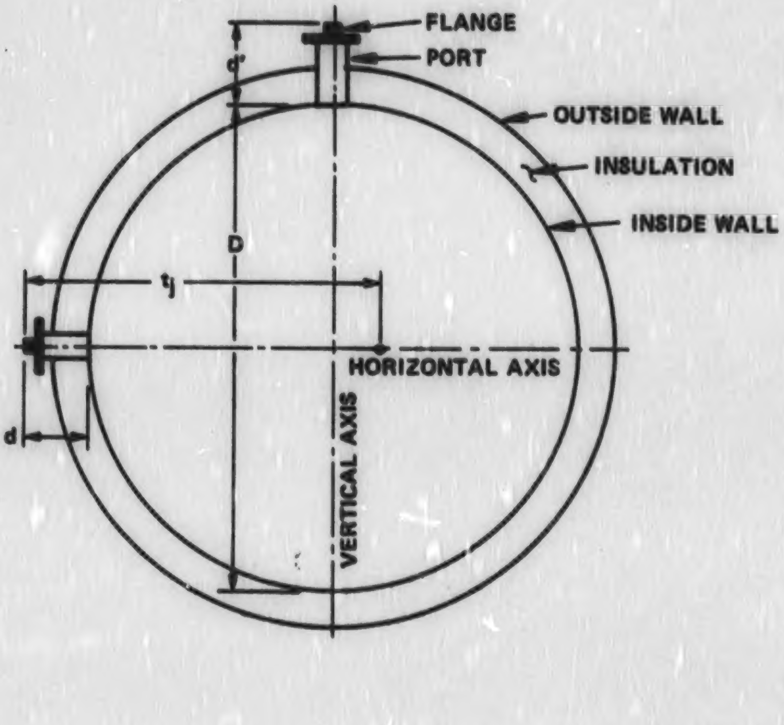
where

d = distance from the inside of the duct to the top of the flange
D = inside diameter of the duct
α_i = is given by:

$$\alpha_i = (D/2)\ \sqrt{(2n_i - 1)/K} \quad \text{for } n_i = 1, 2, \ldots\ \ell$$

where

K = number of traverse points on a given axis, an even integer
ℓ = $K/2$
n_i = an integer having values 1, 2, ... ℓ


FLANGE
PORT
d'
OUTSIDE WALL
INSULATION
INSIDE WALL
D
t_j
HORIZONTAL AXIS
d
VERTICAL AXIS

Thus for K traverse points on a given axis (i.e., horizontal or vertical) we have "flange to point" distances, t_j, as follow:

$$(\text{let } C = d + D/2)$$

$$\begin{aligned} t_1 &= C - \alpha_\ell & t_k &= C + \alpha_\ell \\ t_2 &= C - \alpha_{\ell-1} & t_{k-1} &= C + \alpha_{\ell-1} \\ t_3 &= C - \alpha_{\ell-2} & t_{k-2} &= C + \alpha_{\ell-2} \\ &\vdots & &\vdots \\ t_{\ell-1} &= C - \alpha_2 & t_{\ell+2} &= C + \alpha_2 \\ t_\ell &= C - \alpha_1 & t_{\ell+1} &= C + \alpha_1 \end{aligned}$$

Note:
- The output (displayed) values of distances to traverse points alternate symmetrically across the stack centerline beginning at the outermost point from the stack centerline as R/S is actuated.
- The choice of units for D and d fix the units of t_j. Do not mix units.
- If "d" is the same for both ports (horizontal axis and vertical axis, see illustration) the same t_j values may be used on either axis. If $d \neq d'$, a new set (t_j') must be calculated using d'.

Reference: Standard Method for Sampling Stacks for Particulate Matter, D 2928-71. In: 1971 Annual Book of ASTM Standards, Part 23. Philadelphia, Pa., 1971, p. 835.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 03	RCL 3
02	02	2
03	71	÷
04	01	1
05	51	+
06	23 00	STO 0
07	24 01	RCL 1
08	24 02	RCL 2
09	02	2
10	71	÷
11	51	+
12	23 04	STO 4
13	24 00	RCL 0
14	01	1
15	41	−
16	15 71	g x=0
17	13 40	GTO 40
18	23 00	STO 0
19	02	2
20	61	x
21	01	1
22	41	−
23	24 03	RCL 3
24	71	÷

DISPLAY		KEY ENTRY
LINE	CODE	
25	14 02	f$\sqrt{x}$
26	24 02	RCL 2
27	61	x
28	02	2
29	71	÷
30	23 06	STO 6
31	24 04	RCL 4
32	24 06	RCL 6
33	41	−
34	74	R/S
35	24 04	RCL 4
36	24 06	RCL 6
37	51	+
38	74	R/S
39	13 13	GTO 13
40	00	0
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	ℓ
R_1	d
R_2	D
R_3	K
R_4	(d + D/2)
R_5	α_i
R_6	
R_7	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initalize			f	PRGM	
3	a. Store variables		d	STO	1	
			D	STO	2	
			K	STO	3	
	b. Compute distances	01		R/S		t_i
	Do i = 1, ℓ	35		R/S		*
	0.0 indicates END					

* t_{K+1-i}

Example:

d = 1.5 feet
D = 20 feet
K = 10 (i.e., 10 points on the horizontal axis)

(i = 1)	$t_1 = 2.01$	(K = 10)	$t_{10} = 20.99$
	$t_2 = 3.13$		$t_9 = 19.87$
	$t_3 = 4.43$		$t_8 = 18.57$
	$t_4 = 6.02$		$t_7 = 16.98$
	$t_5 = 8.34$		$t_6 = 14.66$

0.00 indicates END

METHOD 2

DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the coefficient (C_p) for a Type S pitot tube can be determined by simultaneous readings from a standard type pitot tube from the following equation:

$$C_{p_{test}} = C_{p_{std}} \sqrt{\frac{\Delta p_{std}}{\Delta p_{test}}} \qquad (2\text{-}1)$$

where

$C_{p_{test}}$ = pitot tube coefficient of Type S pitot tube, dimensionless

$C_{p_{std}}$ = pitot tube coefficient of standard (if unknown use 0.99) type pitot tube, dimensionless

Δp_{std} = velocity head measured by standard type pitot tube, inches H_2O

Δp_{test} = velocity head measured by Type S pitot tube, inches H_2O

Using a calibrated Type S pitot tube, the stack gas velocity, $(V_s)_{avg}$, can be calculated from:

$$(V_s)_{avg} = K_p \; C_{p_{test}} \; (\sqrt{\Delta p})_{avg} \sqrt{\frac{(T_s)_{avg}}{P_s \; M_s}} \qquad (2\text{-}2)$$

where

$(V_s)_{avg}$ = average stack gas velocity, actual f.p.s.

K_p = 85.48 for the units given herein

$C_{p_{test}}$ = pitot tube coefficient, dimensionless

$(T_s)_{avg}$ = average absolute stack gas temperature, °R

$(\sqrt{\Delta p})_{avg}$ = average velocity head of stack gas, inches H_2O

P_s = stack gas pressure, absolute, inches Hg

M_s = molecular weight of stack gas, wet, lb/lb-mole, given by:

$$M_s = M_d(1\text{-}B_{wo}) + 18\, B_{wo}$$

where

M_d = dry molecular weight of stack gas (from Method 3), lb/lb-mole

B_{wo} = fraction by volume of water vapor in the gas stream (from Method 4), dimensionless

The stack gas volumetric flow rate, Q_s, is given by:

$$Q_s = 3600\ (1\text{-}B_{wo})(V_s)_{avg}\ \ A\left(\frac{T_{std}}{(T_s)_{avg}}\right)\left(\frac{P_s}{P_{std}}\right) \qquad (2\text{-}3)$$

where

Q_s = volumetric flow rate, dry basis, standard (normal) conditions (528°R, 29.92 inches Hg), ft^3/hr (i.e., DSCFH)

A = cross-sectional area of stack, ft^3

T_{std} = 528°R, absolute temperature at standard (normal) conditions

P_{std} = 29.92 inches Hg, absolute pressure at standard (normal) conditions

B_{wo}, $(V_s)_{avg}$, $(T_s)_{avg}$ and P_s are as defined above

Note:
- 1.00 ft/sec = 0.3048 m/sec
- 1.00 ft^3/hr = 28.32 l/hr = 0.02832 m^3/hr
- For longer display of point velocities, replace g NOP lines 18 through 21 with f PAUSE as desired. For halt to display point velocities replace f PAUSE, line 17, with R/S.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	71	÷
02	14 02	f $\sqrt{x}$
03	61	x
04	23 03	STO 3
05	74	R/S
06	24 01	RCL 1
07	61	x
08	21	x⇌y
09	23 06	STO 6
10	34	CLX
11	01	1
12	24 01	RCL 1
13	41	−
14	24 00	RCL 0
15	61	x
16	51	+
17	14 74	f PAUSE
18	15 74	g NOP
19	15 74	g NOP
20	15 74	g NOP
21	15 74	g NOP
22	24 06	RCL 6
23	21	x⇌y
24	71	÷

DISPLAY		KEY ENTRY
LINE	CODE	
25	24 04	RCL 4
26	71	÷
27	14 02	f $\sqrt{x}$
28	61	x
29	24 03	RCL 3
30	61	x
31	24 02	RCL 2
32	61	x
33	23 07	STO 7
34	74	R/S
35	61	x
36	24 04	RCL 4
37	61	x
38	24 06	RCL 6
39	71	÷
40	24 05	RCL 5
41	61	x
42	24 07	RCL 7
43	61	x
44	01	1
45	24 01	RCL 1
46	41	−
47	61	x
48	74	R/S
49	13 06	GTO 06

REGISTERS	
R_0	M_d
R_1	B_{wo}
R_2	85.48
R_3	C_p
R_4	P_s
R_5	A
R_6	$(T_s)_{avg}$
R_7	$(V_s)_{avg}$

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute $C_{p_{test}}$	01	$C_{p_{std}}$	↑		
			Δp_{std}	↑		
			Δp_{test}	R/S		$C_{p_{test}}$
4	Compute M_d		%CO	↑		
			$\%N_2$	+		
			0.28	x		
			$\%O_2$	↑		
			0.32	x	+	
			$\%CO_2$	↑		
			0.44	x	+	M_d
5	Compute $(V_s)_{avg}$	06	M_d	STO	0	
			B_{wo}	STO	1	
			85.48	STO	2	
			(C_p)	STO	3	
			P_s	STO	4	
			$(\sqrt{\Delta p})_{avg}$	↑		
	(°R)		$(T_s)_{avg}$	↑		
			460	+		
			18	R/S		$[M_s]$
						$(V_s)_{avg}$
6	Compute Q_s	35	A	STO	5	
			(B_{wo})	STO	1	
			(P_s)	STO	4	
			$((T_s)_{avg})$	STO	6	
			$((V_s)_{avg})$	STO	7	
			3600	↑		
			17.71	R/S		Q_s

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
7	Convert SDCFH → SDLPH		28.32	x		liters
8	For subsequent traverse sets where					
	$C_{p_{test}}$ and M_d are the same					
	"GTO 06" and start at Step 5.					

Example:

$Cp_{std} = 0.99$
$\Delta p_{std} = 0.31$ inches H_2O
$\Delta p_{test} = 0.42$ inches H_2O

→ $C_{p_{test}} = 8.51 \times 10^{-1}$

%CO = 1%
$\%N_2 = 79\%$
0.28
$\%O_2 = 6\%$
0.32
$\%CO_2 = 13\%$
0.44

→ $M_d = 3.00 \times 10^{1}$ lb/lb-mole
STO 0

$B_{wo} = 0.10$
85.48
$P_s = 29.00$ inches Hg
$(\sqrt{\Delta p})_{avg} = 0.59$ inches $H_2O^{1/2}$
$(T_s)_{avg} = 350°F$
460
18

→ $[M_s] = 2.88 \times 10^{1}$ (pause)
$(V_s)_{avg} = 4.22 \times 10^{1}$ f.p.s.

$A = 1{,}200\ ft^2$
3600
17.71

→ $Q_s = 1.04 \times 10^{8}$ SDCFH
($= 2.95 \times 10^{9}$ SDLPH)

METHOD 3

GAS ANALYSIS FOR CARBON DIOXIDE, EXCESS AIR, AND DRY MOLECULAR WEIGHT

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the percent excess air, %EA, is given by the following:

$$\%EA = \frac{(\%O_2) - 0.5\,(\%CO)}{0.264\,(\%N_2) - (\%O_2) + 0.5\,(\%CO)} \times 100\% \qquad (3\text{-}1)$$

where

$\%EA$ = percent excess air
$\%O_2$ = percent oxygen by volume, dry basis
$\%N_2$ = percent nitrogen by volume, dry basis
$\%CO$ = percent carbon monoxide by volume, dry basis
0.264 = ratio of oxygen to nitrogen in air by volume

The dry molecular weight, M_d, is given by:

$$M_d = 0.44\,(\%CO_2) + 0.32\,(\%O_2) + 0.28\,(\%N_2 + \%CO) \qquad (3\text{-}2)$$

where

M_d = dry molecular weight, lb/lb-mole
$\%CO_2$ = percent carbon dioxide by volume, dry basis
$\%O_2$ = percent oxygen by volume, dry basis
$\%N_2$ = percent nitrogen by volume, dry basis
$\%CO$ = percent carbon monoxide by volume, dry basis
0.44 = molecular weight of carbon dioxide divided by 100
0.32 = molecular weight of oxygen divided by 100
0.28 = molecular weight of nitrogen and CO divided by 100

Note: 1.0 lb/lb-mole = 1.0 gm/gm-mole = 1.0 amu

Example:

$\%CO$ = 1%
$\%N_2$ = 79%
$\%O_2$ = 4%
$\%CO_2$ = 16%

→ $\%EA$ = 20.17%
M_d = 30.72 lb/lb-mole

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 03	RCL 3
02	24 01	RCL 1
03	73	·
04	05	5
05	61	x
06	41	−
07	24 02	RCL 2
08	73	·
09	02	2
10	06	6
11	04	4
12	61	x
13	24 03	RCL 3
14	41	−
15	24 01	RCL 1
16	73	·
17	05	5
18	61	x
19	51	+
20	71	÷
21	01	1
22	00	0
23	00	0
24	61	x

DISPLAY		KEY ENTRY
LINE	CODE	
25	74	R/S
26	24 02	RCL 2
27	24 01	RCL 1
28	51	+
29	73	·
30	02	2
31	08	8
32	61	x
33	24 03	RCL 3
34	73	·
35	03	3
36	02	2
37	61	x
38	51	+
39	24 04	RCL 4
40	73	·
41	04	4
42	04	4
43	61	x
44	51	+
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	
R_1	%CO
R_2	%N_2
R_3	%O_2
R_4	%CO_2
R_5	
R_6	
R_7	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	a. Store variables		%CO	STO	1	
			%N_2	STO	2	
			%O_2	STO	3	
			%CO_2	STO	4	
	b. Compute %EA	01		R/S		%EA
	c. Compute M_d	26		R/S		M_d
4	For subsequent data sets, change					
	stored values as necessary and					
	repeat Step 3b and 3c					
	respectively.					

METHOD 4

DETERMINATION OF MOISTURE IN STACK GASES

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the volume of water vapor collected, V_{wc}, is given by:

$$V_{wc} = (0.0472\ \text{ft}^3/\text{ml}) \left(V_f - V_i\right) \qquad (4\text{-}1)$$

where

V_{wc} = volume of water vapor collected (standard conditions, 528°R, 29.92 inches Hg), ft³
V_f = final volume of impinger contents, ml
V_i = initial volume of impinger contents, ml

The dry gas volume through the meter, at standard conditions, V_{me}, is given by:

$$V_{me} = (17.65\,°\text{R/in. Hg}) \left(\frac{V_m P_m}{T_m}\right) \qquad (4\text{-}2)$$

where

V_{me} = dry gas volume through meter at standard conditions, ft³
V_m = dry gas volume measured by meter, ft³
P_m = barometric pressure at the dry gas meter, inches Hg
T_m = absolute temperature at meter, °R

The moisture content, B_{wo}, is given by:

$$B_{wo} = \left(\frac{V_{wc}}{V_{wc} + V_{me}}\right) + 0.025 \qquad (4\text{-}3)$$

where

B_{wo} = fraction by volume of water vapor in the gas stream, dimensionless
V_{wc} = volume of water vapor collected (standard conditions), ft³
0.025 = approximate volumetric proportion of water vapor in the gas stream leaving the impingers

V_{me} is as defined in (4-2) above.

Note: 1.00 ft³ = 28.32 liters

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 01	RCL 1
02	24 02	RCL 2
03	41	–
04	73	·
05	00	0
06	04	4
07	07	7
08	04	4
09	61	x
10	23 06	STO 6
11	74	R/S
12	24 03	RCL 3
13	24 04	RCL 4
14	61	x
15	24 05	RCL 5
16	04	4
17	06	6
18	00	0
19	51	+
20	71	÷
21	01	1
22	07	7
23	73	·
24	07	7

DISPLAY		KEY ENTRY
LINE	CODE	
25	01	1
26	61	x
27	23 07	STO 7
28	74	R/S
29	24 06	RCL 6
30	24 06	RCL 6
31	24 07	RCL 7
32	51	+
33	71	÷
34	73	·
35	00	0
36	02	2
37	05	5
38	51	+
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	28.32
R_1	V_f
R_2	V_l
R_3	V_m
R_4	P_m
R_5	T_m
R_6	V_{wc}
R_7	V_{me}

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	a. Store variables		V_f	STO	1	
			V_l	STO	2	
			V_m	STO	3	
			P_m	STO	4	
	(°F)		T_m	STO	5	
	b. Compute V_{wc}	01		R/S		V_{wc}
	c. Compute V_{me}	12		R/S		V_{me}
	d. Compute B_{wo}	29		R/S		B_{wo}

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
4	For subsequent data sets, change					
	stored values as necessary and					
	repeat Steps 3b, 3c, and 3d,					
	respectively.					
5	To convert ft³ → liters					
	a. Store		28.32	STO	0	
	b. Convert		ft³	RCL	0	
				x		liters

Example:

V_f = 12.5 ml (total)
V_l = 10.0 ml (total)
V_m = 1.00 ft³
P_m = 29.00 in. Hg
T_m = 100°F

→ V_{wc} = 0.119 ft³ (= 3.36 liters)
V_{me} = 0.917 ft³ (= 26.0 liters)
B_{wo} = 0.14, dimensionless

METHOD 5

DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

As described in Volume 36, No. 247 Part II of the Federal Register, December 23, 1971, the sample volume measured by the dry gas meter, corrected to standard conditions (68°F, 29.92 inches Hg) is given by:

$$V_{m_{std}} = \left(17.65 \frac{°R}{\text{in. Hg}}\right) V_m \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{T_m}\right) \tag{5-1}$$

where

$V_{m_{std}}$ = volume of gas sample through the dry gas meter (standard conditions), ft^3
V_m = volume of gas sample through the dry gas meter (meter conditions), ft^3
T_m = average dry gas meter temperature, °R
P_{bar} = barometric pressure at the orifice meter, inches Hg
ΔH = average pressure drop across the orifice meter, inches H_2O

The volume of water vapor in the gas sample, corrected to standard conditions, is given by:

$$V_{w_{std}} = \left(0.0472 \frac{ft^3}{ml}\right) V_{\ell_c} \tag{5-2}$$

where

$V_{w_{std}}$ = volume of water vapor in the gas sample (standard conditions), ft^3
V_{ℓ_c} = total volume of liquid collected in impingers and silica gel, ml

The fraction by volume of water vapor in the gas stream is given by:

$$B_{wo} = \frac{V_{w_{std}}}{V_{m_{std}} + V_{w_{std}}} \tag{5-3}$$

where

B_{wo} = fraction by volume of water vapor in the gas stream, dimensionless
$V_{m_{std}}$ and $V_{w_{std}}$ are as given in equations (5-1) and (5-2) respectively.

The concentration of particulate matter in stack gas, dry basis, is given by:

$$c'_s = \left(0.0154\ \frac{gr}{mg}\right)\left(\frac{M_n}{V_{m_{std}}}\right) \tag{5-4}$$

where

c'_s = concentration of particulate matter in stack gas, gr/S.C.F., dry basis
M_n = total amount of particulate matter collected, mg
$V_{m_{std}}$ is as given by equation (5-1).

Changing units, we can express c'_s in terms of lb/S.C.F., dry basis, as follows:

$$c_s = \left(2.205 \times 10^{-6}\ \frac{lb}{mg}\right)\frac{M_n}{V_{m_{std}}} \tag{5-5}$$

where

c_s = concentration of particulate matter in stack gas, lb/S.C.F., dry basis
M_n and $V_{m_{std}}$ are as given in equation (5-4).

We can also express c'_s in terms of gm/SCM, dry basis, as follows:

$$c''_s = \left(0.03532\ \frac{gm \cdot SCF}{mg \cdot SCM}\right)\frac{M_n}{V_{m_{std}}}$$

where

c''_s = concentration of particulate matter in stack gas, gm/SCM, dry basis
M_n and $V_{m_{std}}$ are as given in equation (5-4).

The percent isokinetic sampling is given by:

$$I = \frac{\left(1.677\ \frac{min\%}{sec}\right)T_s\left[\left(0.00267\ \frac{in.\ Hg\text{-}ft^3}{ml\text{-}^\circ R}\right)V_{\ell c} + \frac{V_m}{T_m}\left(P_{bar} + \frac{\Delta H}{13.6\ \frac{in.\ H_2O}{in.\ Hg}}\right)\right]}{\theta\, V_s\, P_s\, A_n} \tag{5-6}$$

where

I = percent of isokinetic sampling, %
$V_{\ell c}$ = total volume of liquid collected in impingers and silica gel, ml
V_m = volume of gas sample through the dry gas meter (meter conditions), ft^3
T_m = absolute average dry gas meter temperature, °R
P_{bar} = barometric pressure at sampling site, inches, Hg
ΔH = average pressure drop across the orifice, inches H_2O
T_s = absolute average stack gas temperature, °R
θ = total sampling time, min
V_s = stack gas velocity (calculated by Method 2, Equation 2-2), ft/sec
P_s = absolute stack gas pressure, inches Hg
A_n = cross-sectional area of nozzle, ft^2

Note:
- $1.00\ \text{gr/ft}^3 = 2.288\ \text{gm/m}^3$
- $1.00\ \text{lb/ft}^3 = 1.602 \times 10^4\ \text{gm/m}^3$

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 03	RCL 3
02	24 02	RCL 2
03	51	+
04	24 04	RCL 4
05	71	÷
06	24 01	RCL 1
07	61	x
08	61	x
09	23 07	STO 7
10	74	R/S
11	24 05	RCL 5
12	61	x
13	74	R/S
14	31	↑
15	31	↑
16	24 07	RCL 7
17	51	+
18	71	÷
19	74	R/S
20	23 00	STO 0
21	34	CLX
22	24 03	RCL 3
23	24 02	RCL 2
24	51	+

DISPLAY		KEY ENTRY
LINE	CODE	
25	24 01	RCL 1
26	61	x
27	24 04	RCL 4
28	71	÷
29	24 05	RCL 5
30	73	.
31	00	0
32	00	0
33	02	2
34	06	6
35	07	7
36	61	x
37	51	+
38	24 00	RCL 0
39	71	÷
40	01	1
41	73	.
42	06	6
43	07	7
44	07	7
45	61	x
46	61	x
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	(work)
R_1	V_m
R_2	P_{bar}
R_3	ΔH
R_4	T_m
R_5	V_{ℓ_c}
R_6	M_n
R_7	$V_{m_{std}}$

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: initialize			f	PRGM	
3	a. Store variables		V_m	STO	1	
			P_{bar}	STO	2	
			ΔH	↑		
			13.6	÷		
				STO	3	
	(°F)		T_m	↑		
			460	+		
				STO	4	
			V_{ℓ_c}	STO	5	
			M_n	STO	6	
	b. Compute $V_{m_{std}}$	01	17.71	R/S		$V_{m_{std}}$
	c. Compute $V_{w_{std}}$	11	0.0474	R/S		$V_{w_{std}}$
	d. Compute B_{wo}	14		R/S		B_{wo}
	e. Compute c'_s (gr/ft^3)		0.0154	RCL	6	
				×		
				RCL	7	
				÷		c'_s
	f. Compute c_s(lb/ft^3)		2.205×10^{-6}	RCL	6	
				×		
				RCL	7	
				÷		c_s
	g. Compute c''_s (gm/m^3)		0.03532	RCL	6	
				×		
				RCL	7	
				÷		c''_s
5	Compute I	20	(V_m)	STO	1	
			(P_{bar})	STO	2	
	(in. H_2O)		(ΔH)	STO	3	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
			(T_m)	STO	4	
			$(V\ell_c)$	STO	5	
	(°F)		T_s	↑		
			460	+		
			θ	↑		
			V_s	×		
			P_s	×		
			A_n	×	R/S	I

Example:

$V_m = 100\ ft^3$
$P_{bar} = 29.5$ inches Hg
$\Delta H = 5.0$ inches H_2O
13.6
$T_m = 100°F$
460
$V\ell_c = 50$ ml
$M_n = 100$ mg
17.71

→ $V_{m_{std}} = 9.45 \times 10^1$ SDCF

0.0474

→ $V_{w_{std}} = 2.37$ SDCF
$B_{wo} = 2.45 \times 10^{-2}$ (dimensionless)

0.0154
(M_n)
$(V_{m_{std}})$

→ $c'_s = 1.63 \times 10^{-2}$ gr/SDCF

2.205×10^{-6}
(M_n)
$(V_{m_{std}})$

→ $c_s = 2.33 \times 10^{-6}$ lb/SDCF

0.03532
(M_n)
$(V_{m_{std}})$

→ $c''_s = 3.74 \times 10^{-2}$ gm/SDCM

T_s = 300°F

460

θ = 100 min

V_s = 15.00 ft/sec

P_s = 29.00 inches Hg

A_n = 0.00136 ft^2

$\rightarrow$ $I = 1.18 \times 10^2\%$

(Note: In the above example I > 110%, thus the test results would be rejected and the test repeated.)

METHOD 6

DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the volume of the gas sample through the dry gas meter, corrected to standard conditions (528°R, 29.92 inches Hg), $V_{m_{std}}$, is given by:

$$V_{m_{std}} = \left(17.65 \ \frac{°R}{\text{in. Hg}}\right)\left(\frac{V_m P_{bar}}{T_m}\right) \qquad (6\text{-}1)$$

where

$V_{m_{std}}$ = volume of gas sample through the dry gas meter (standard conditions), ft^3

V_m = volume of gas sample through the dry gas meter (meter conditions), ft^3

T_m = average dry gas meter temperature, °R

P_{bar} = barometric pressure at the orifice meter, inches Hg

The concentration of sulfur dioxide at standard conditions, dry basis is given by.

$$C_{SO_2} = \left(7.05 \times 10^{-5} \ \frac{\text{lb-l}}{\text{g-ml}}\right) \frac{(V_t - V_{tb}) \ N \left(\frac{V_{soln}}{V_a}\right)}{V_{m_{std}}} \qquad (6\text{-}2)$$

where

C_{SO_2} = concentration of sulfur dioxide at standard conditions, dry basis, lb/ft^3

7.05×10^{-5} = conversion factor, including the number of grams per gram equivalent of sulfur dioxide (32 g/g-eq.), 453.6 g/lb, and 1,000 ml/l, lb-l/g-ml

V_t = volume of barium perchlorate titrant used for the sample, ml

V_{tb} = volume of barium perchlorate titrant used for the blank, ml

N = normality of barium perchlorate titrant, g-eq/l

V_{soln} = total solution volume of sulfur dioxide, 50 ml

V_a = volume of sample aliquot titrated, ml

$V_{m_{std}}$ = volume of gas sample through the dry gas meter (standard conditions), ft^3

Note: $1.00 \ lb/ft^3 = 1.602 \times 10^4 \ gm/m^3$

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 01	RCL 1
02	61	x
03	24 02	RCL 2
04	71	÷
05	01	1
06	07	7
07	73	·
08	07	7
09	01	1
10	61	x
11	23 03	STO 3
12	74	R/S
13	24 04	RCL 4
14	24 05	RCL 5
15	41	–
16	24 06	RCL 6
17	61	x
18	24 07	RCL 7
19	61	x
20	24 00	RCL 0
21	71	÷
22	24 03	RCL 3
23	71	÷
24	07	7
25	00	0
26	05	5
27	33	EEX
28	32	CHS
29	07	7
30	61	x
31	74	R/S
32	01	1
33	06	6
34	00	0
35	02	2
36	00	0
37	61	x
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	V_s
R_1	P_{bar}
R_2	T_m
R_3	$V_{m_{std}}$
R_4	V_t
R_5	V_{tb}
R_6	N
R_7	V_{soln}

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	a. Store variables		P_{bar}	STO	1	
	(°F)		T_m	↑		
			460	+		
				STO	2	
	b. Compute $V_{m_{std}}$	01	V_m	R/S		$V_{m_{std}}$
4	Compute C_{SO_2}					
	a. Store variables		($V_{m_{std}}$)	STO	3	
			V_t	STO	4	
			V_{tb}	STO	5	
			N	STO	6	
			V_{soln}	STO	7	
			V_a	STO	0	
	b. Compute C_{SO_2} (lb/ft³)	13		R/S		C_{SO_2}
	c. Convert lb/ft³ → gm/m³	32	lb/ft³	R/S		gm/m³

Example:

P_{bar} = 26.00 inches Hg
T_m = 100°F
460
V_m = 1.77 ft³

→ $V_{m_{std}}$ = 1.46 ft³

V_t = 5 ml
V_{tb} = 0.1 ml
N = 0.005 ml
V_{soln} = 50 ml
V_a = 2 ml

→ $C_{SO_2} = 2.97 \times 10^{-5}$ lb/ft³
(= 4.75×10^{-1} gm/m³)

METHOD 7

DETERMINATION OF NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES

As described in Volume 36, No. 247, Part II of the Federal Register, December 23, 1971, the sample volume corrected to standard conditions (528°R, 29.92 inches Hg) is given by:

$$V_{sc} = \left(17.65 \frac{^{\circ}R}{\text{in. Hg}}\right)\left(V_f - 25 \text{ ml}\right)\left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) \qquad (7\text{-}1)$$

where

V_{sc} = sample volume at standard conditions (dry basis), ml
V_f = volume of flask and valve, ml
25 ml = volume of absorbing solution
P_f = final absolute pressure of flask, inches Hg
P_i = initial absolute pressure of flask, inches Hg
T_f = final absolute temperature of flask, °R
T_i = initial absolute temperature of flask, °R

The concentration of NO_x as NO_2 (dry basis) is given by:

$$C = \left(6.2 \times 10^{-5} \frac{\text{lb/SCF}}{\text{g/ml}}\right)\left(\frac{m}{V_{sc}}\right) \qquad (7\text{-}2)$$

where

C = concentration of NO_x as NO_2 (dry basis), lb/ft^3, standard conditions (i.e., lb/DSCF)
m = mass of NO_2 in gas sample, μgm
V_{sc} = sample volume at standard conditions (dry basis), ml

Note: 1.00 lb/DSCF = 1.602×10^4 gm/DSCM

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 02	RCL 2
02	24 03	RCL 3
03	71	+
04	24 04	RCL 4
05	24 05	RCL 5
06	71	+
07	41	−
08	24 01	RCL 1
09	02	2
10	05	5
11	41	−
12	61	x
13	01	1
14	07	7
15	73	.
16	07	7
17	01	1
18	61	x
19	23 07	STO 7
20	74	R/S
21	24 06	RCL 6
22	24 07	RCL 7
23	71	+
24	06	6
25	02	2
26	33	EEX
27	32	CHS
28	06	6
29	61	x
30	74	R/S
31	01	1
32	73	.
33	06	6
34	00	0
35	02	2
36	33	EEX
37	04	4
38	61	x
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	
R_1	V_f
R_2	P_f
R_3	T_f
R_4	P_i
R_5	T_i
R_6	m
R_7	V_{sc}

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	a. Correct sample volume to dry,					
	standard conditions	01	V_f	STO	1	
			P_f	STO	2	
	(°F)		T_f	↑		
			460	+		
				STO	3	
			P_i	STO	4	
	(°F)		T_i	↑		
			460	+		
				STO	5	
				R/S		V_{sc}
	b. Compute concentration of NO_x	21	m	STO	6	
	as NO_2		(V_{sc})	STO	7	
				R/S		C
	c. Convert lb/DSCF → gm/DSCM	31	lb/DSCF	R/S		gm/DSCM

Example:

V_f = 2,000 ml
P_f = 25.00 inches Hg
T_f = 120°F
460
P_i = 5.00 inches Hg
T_i = 70°F
460

→ $V_{sc} = 1.18 \times 10^3$ ml

m = 5.0 μg

→ $C = 2.63 \times 10^{-7}$ lb/DSCF
(= 4.22×10^{-3} gm/DSCM)

METHOD 8

DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

As described in Volume 36, No. 247 Part II of the Federal Register, December 23, 1971, the dry gas meter volume corrected to standard conditions (528°R, 29.92 inches Hg) is given by:

$$V_{m_{std}} = \left(17.65 \ \frac{°R}{\text{in. Hg}}\right) V_m \left(\frac{P_{bar} + \frac{\Delta H}{13.6}}{T_m}\right) \qquad (8\text{-}1)$$

where

$V_{m_{std}}$ = volume of gas sample through the dry gas meter, standard conditions, ft^3
V_m = volume of gas sample through the dry gas meter, meter conditions, ft^3
T_m = average dry gas meter temperature, °R
P_{bar} = barometric pressure at the orifice meter, inches Hg
ΔH = pressure drop across the orifice meter, inches H_2O

The concentration of sulfuric acid (standard conditions, dry) is given by:

$$C_{H_2SO_4} = 1.08 \times 10^{-4} \ \frac{\text{lb-l}}{\text{g-ml}} \times (\beta) \qquad (8\text{-}2)$$

where

$C_{H_2SO_4}$ = concentration of sulfuric acid at standard conditions, dry basis, lb/ft^3; (i.e., lb/DSCF)
1.08×10^{-6} = conversion factor including the number of grams per gram equivalent of sulfuric acid (49 g/g-eq.), 458.6 g/lb, and 1,000 ml/l, lb-l/g-ml

β is given by:

$$\beta = \frac{(V_t - V_{tb}) \ N \ \frac{V_{soln}}{V_a}}{V_{m_{std}}}$$

where

V_t = volume of barium perchlorate titrant used for the sample, ml
V_{tb} = volume of barium perchlorate titrant used for the blank, ml
N = normality of barium perchlorate titrant, g-eq./l
V_{soln} = total solution volume of:
- equ. (8-2): sulfuric acid, ml (first impinger and filter)
- equ. (8-3): sulfur dioxide, ml (second and third impingers)

V_a = volume of sample aliquot titrated, ml
$V_{m_{std}}$ = volume of gas sampled through the dry gas meter, standard conditions, ft^3, see equation (8-1)

The concentration of sulfur dioxide (standard conditions, dry) is given by:

$$C_{SO_2} = 7.05 \times 10^{-5} \frac{\text{lb-l}}{\text{g-ml}} \times (\beta) \qquad (8\text{-}3)$$

where

C_{SO_2} = concentration of sulfur dioxide at standard conditions, dry basis, lb/ft^3, (i.e., lb/DSCF)
7.05×10^{-5} = conversion factor including the number of grams per gram equivalent of sulfur dioxide (32 g/g-eq)

Note: $1.00\ lb/ft^3 = 1.602 \times 10^4\ gm/m^3$

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	71	÷
02	24 01	RCL 1
03	51	+
04	24 02	RCL 2
05	71	÷
06	61	x
07	01	1
08	07	7
09	73	•
10	07	7
11	01	1
12	61	x
13	23 03	STO 3
14	74	R/S
15	24 04	RCL 4
16	24 05	RCL 5
17	41	–
18	61	x
19	24 06	RCL 6
20	61	x
21	24 07	RCL 7
22	71	÷
23	24 03	RCL 3
24	71	÷
25	74	R/S
26	13 15	GTO 15
27	13 00	GTO 00
28	13 00	GTO 00
29	13 00	GTO 00
30	13 00	GTO 00
31	13 00	GTO 00
32	13 00	GTO 00
33	13 00	GTO 00
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	V_{soln}
R_1	P_{bar}
R_2	T_m
R_3	$V_{m_{std}}$
R_4	V_t
R_5	V_{tb}
R_6	N
R_7	V_a

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	For $V_{m_{std}}$					
	a. Store variables		P_{bar}	STO	1	
	(°F)		T_m	↑		
			460	+		
				STO	2	
	b. Compute $V_{m_{std}}$	01	V_m	↑		
			ΔH	↑		
			13.6	R/S		$V_{m_{std}}$
4	For $C_{H_2SO_4}$	15	$(V_{m_{std}})$	STO	3	
			V_t	STO	4	
			V_{tb}	STO	5	
			N	STO	6	
			V_a	STO	7	
			V_{soln}	R/S		$\beta_{H_2SO_4}$
	(lb/ft³)		1.08×10^{-4}	x		$C_{H_2SO_4}$
5	For C_{SO_2}	25	$(V_{m_{std}})$	STO	3	
	(change stored variables as		V_t	STO	4	
	required)		V_{tb}	STO	5	
			N	STO	6	
			V_a	STO	7	
			V_{soln}	R/S		β_{SO_2}
	(lb/ft³)		7.06×10^{-5}	x		C_{SO_2}
6	To convert lb/ft³ → gm/m³		lb/ft³	↑		
			1.602×10^{4}	x		gm/m³

Example:

P_{bar} = 29.00 inches Hg

T_m = 100°F

460

V_m = 100 ft^3

ΔH = 5.00 inches H_2O

13.6

→ $V_{m_{std}}$ = 9.29×10^1 ft^3

V_t = 4 ml

V_{tb} = 0.1 ml

N = 0.005 g-eq/l

V_a = 2 ml

V_{soln} = 50 ml

→ $\beta_{H_2SO_4}$ = 5.25×10^{-3}

1.08×10^{-4}

→ $C_{H_2SO_4}$ = 5.67×10^{-7} lb/ft^3

(= 9.08×10^{-3} gm/m^3)

V_t = 6 ml

V_{tb} = 0.1 ml

N = 0.005 g-eq/l

V_a = 2 ml

V_{soln} = 75 ml

→ β_{SO_2} = 1.19×10^{-3}

7.05×10^{-5}

→ C_{SO_2} = 8.40×10^{-7} lb/ft

(= 1.35×10^{-2} gm/m^3)

CASCADE IMPACTOR OPERATION: PITOT TUBE DATA REDUCTION, NOZZLE AND FLOW RATE SELECTION, FLOW METERING PARAMETERS

The following three programs can be used to determine impactor run data parameters. APol-09A is used to compute point velocities from pitot data, and the average stack gas velocity over the entire traverse. This is then used to select the correct nozzle for isokinetic sampling. For a low flow rate impactor set up using two calibrated orifices (Figure 9-A), the run parameters (ΔP_{sy}, ΔH, $\Delta H'$) can be calculated with program APol-09B (Example 2). For a high flow rate impactor set up using one calibrated orifice and a gas meter (Figure 9-B), the run parameters (ΔP_{sy}, ΔH, t) can be calculated using program APol-09C (Example 3).

The mean molecular weight, dry (M_d) of flue gas is given by:

$$M_d = 28(B_{N_2} + B_{CO}) + 32\ B_{O_2} + 44\ B_{CO_2}$$

where

B_{N_2}, B_{CO}, B_{O_2}, B_{CO_2}, are the dry volumetric fractions for N_2, CO, O_2, and CO_2 respectively

The mean molecular weight, wet, of flue gas, M_s, is given by:

$$M_s = M_d\ (1-B_{wo}) + 18\ B_{wo}$$

where

B_{wo} = volumetric fraction of water, dimensionless

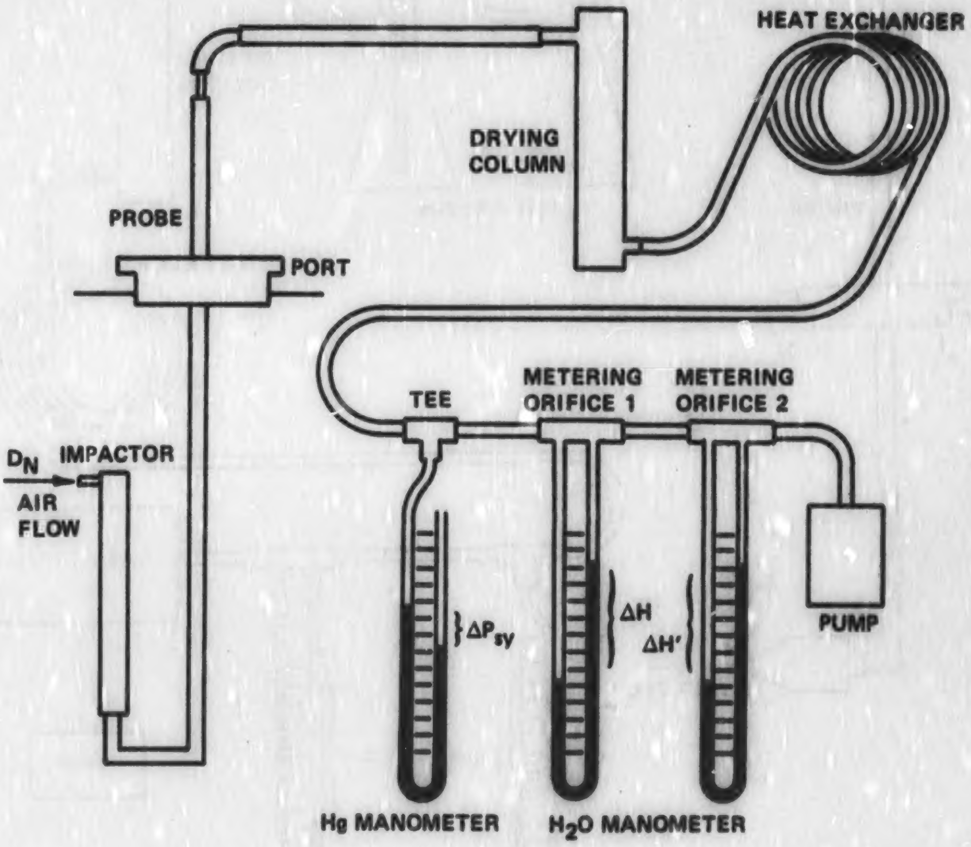

HEAT EXCHANGER
DRYING COLUMN
PROBE
PORT
TEE
METERING ORIFICE 1
METERING ORIFICE 2
D_N
IMPACTOR
AIR FLOW
PUMP
ΔP_{sy}
ΔH
$\Delta H'$
Hg MANOMETER
H_2O MANOMETER

Figure 9-A. A Typical Setup for Low Flow Rate Impactors Using Two Calibrated Orifice Flow Meters

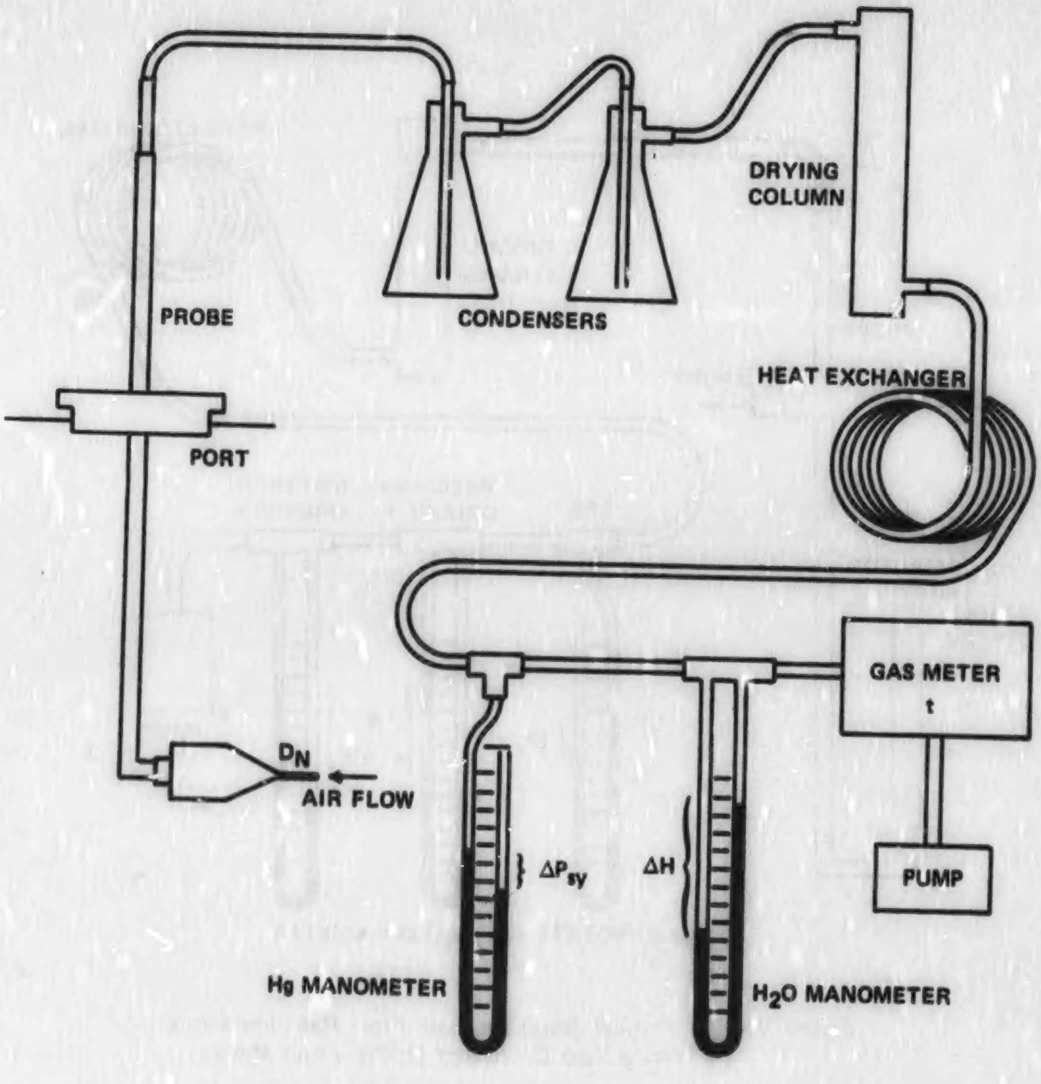

PROBE
CONDENSERS
DRYING COLUMN
HEAT EXCHANGER
PORT
D_N
AIR FLOW
GAS METER
t
PUMP
ΔP_{sy}
ΔH
Hg MANOMETER
H_2O MANOMETER

Figure 9-B. A Typical Setup for High Flow Rate Impactors Using a Calibrated Orifice and a Dry Gas Meter

The point velocity (V_i) as determined by a Type S pitot tube is given by:

$$V_i = \theta \sqrt{\Delta p_i \ T_i} \tag{9-1}$$

where

Δp_i = velocity pressure (inches H_2O) at point i
T_i = temperature (°R) at point i
θ = pitot-gas composition factor, given by:

$$\theta = 2.9 \ C_p \ \sqrt{29.92 \frac{R'}{P_s}}$$

where

$$R' = \frac{28.95 \text{ amu}}{M_s}$$

$$P_s = P_{bar} + \left(\frac{\pm \Delta P_s}{13.6}\right)$$

where

P_{bar} = ambient pressure, inches Hg
$\pm \Delta P_s$ = stack pressure differential, inches H_2O
C_p = pitot constant, dimensionless
M_s is as defined above.

Average velocity, $(V_s)_{avg}$, is given by:

$$(V_s)_{avg} = \frac{1}{n} \ \Sigma \ V_i \ (i = 1,n)$$

Average temperature, $(T_s)_{avg}$, is given by:

$$(T_s)_{avg} = \frac{1}{n} \ \Sigma \ T_i \ (i = 1,n)$$

The impactor flow rate, Q_I, is given by:

$$Q_I = 5.072 \times 10^{-4} \ (V_s)_{avg} \ \pi \ D_N^2$$

where

Q_I = impactor flow rate, ft^3/min (i.e., CFM)
$(V_s)_{avg}$ = average velocity, ft/sec
D_N = nozzle diameter, millimeters

The pressure drop across the orifice required to obtain the desired actual impactor flow rate is given by:

$$\Delta H = \frac{\alpha}{(P_{bar} - \Delta P_{sy})} \tag{9-2a}$$

where

ΔH = pressure drop across the orifice required to obtain the desired actual impactor flow rate, inches H_2O

P_{bar} = ambient pressure, inches Hg

ΔP_{sy} = pressure differential to ambient, inches Hg, immediately upstream from the orifice

α = intermediate value, given by:

$$\alpha = \frac{\beta \; c_c}{(Q_{cal})^2} \tag{9-2b}$$

where

Q_{cal} = calibration flow rate (at ΔP_c, T_c, P_c), ACFM

c_c = orifice calibration constant given by:

$$c_c = \frac{T_c \, \Delta H_c}{P_c \, M_c} \tag{9-2c}$$

where

T_c = calibration temperature, °R

P_c = calibration pressure, inches Hg

ΔH_c = pressure drop (inches H_2O) for which Q_{cal} is taken

M_c = MMW of the calibration gas, amu

(Note: MMW of standard air is 28.97 amu, dry

c_c = 6.260 for T_c = 535°R, P_c = 29.50 in. Hg, ΔH_c = 10 inches H_2O, and M_c = 28.97)

β = intermediate value given by:

$$\beta = \left[\frac{Q_I \, (1 - B_{wo}) \;\; P_s}{(T_s)_{avg}}\right]^2 M_d \;\; T_o \tag{9-2d}$$

where

Q_I = desired actual flow rate, ACFM

$(T_s)_{avg}$ = average stack temperature, °R

B_{wo} = volumetric fraction of water

P_s = stack pressure (inches Hg) as used with θ in Equation (9-1)

M_d = mean molecular weight (MMW) of the flue gas, dry

T_o = orifice temperature, °R

In any given sampling situation either a gas meter or a second orifice will be used, but not both. A gas meter is the preferred instrument when the required sampling flow rate is within the calibration range of the gas meter. Whenever required flow rates are below the minimum flows which can be accurately determined by using a gas meter, a second orifice should be substituted in place of the gas meter and positioned in series with and immediately downstream of the first orifice. Such is normally the case when sampling at the inlet to a gas cleaning device where high concentrations require the use of low flow rate impactors.

When a second orifice is used in series with the first orifice, the pressure drop across the second orifice ($\Delta H'$) is given by:

$$\Delta H' = \frac{\lambda}{P_o'} \tag{9-3a}$$

where

$\Delta H'$ = pressure drop across the second orifice, inches H_2O

P_o' = absolute pressure at this orifice (in. Hg), given by:

$$P_o' = P_{bar} - \left(\Delta P_{sy} + \frac{\Delta H}{13.6}\right) \tag{9-3b}$$

where

ΔH = pressure drop (in. Hg) across the first orifice

P_{bar} and ΔP_{sy} are as defined for equation (9-2) above.

λ = intermediate value given by:

$$\lambda = \frac{\beta\, c'_c}{(Q'_{cal})^2} \tag{9-3c}$$

where

Q'_{cal} = calibration flow rate for this orifice

c'_c = orifice calibration constant for this orifice (see equation 9-2c)

β is defined for equation (9-2d) above.

If a gas meter is used (in place of the second orifice), the time (t, in sec) required for one revolution of the gas meter dial is given by:

$$t = \frac{K}{Q_m} \tag{9-4}$$

where

$K = V_o \times 60$ sec/min

V_o = volume for one revolution, ft³

Q_m = actual flow rate through the gas meter, ft³/min, actual (i.e., ACFM), given by:

$$Q_m = \phi \sqrt{\frac{\Delta H'}{P_o'}}$$

where

ΔH = pressure drop across the imaginary second orifice (Q_m equals $Q'_{orifice}$) as determined by setting $Q'_{cal} = Q_{cal}$ and $c'_c = c_c$ where c_c and P'_o are given by equations (9-2b) and (9-3b) respectively.

(For Q_m in CFM and $V_o = 0.1$ ft³, t in seconds is given by $t = 6/Q_m$)

ϕ = intermediate value given by:

$$\phi = Q_{cal} \sqrt{\left(\frac{T_o}{c_c \; M_d}\right)}$$

Note:
- 1.00 inch = 25.40 mm
- 1 gm/gm-mole = 1 lb/lb-mole = 1 amu
- Program APol-09C assumes a specific value for K. When this value is not appropriate, a new value should be calculated using equations (9-4) and the appropriate value for K entered as program steps in place of the assumed value 6.00.

FOR STACK VELOCITIES AND NOZZLE SELECTION
APol-09A

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 01	RCL 1
02	51	+
03	23 00	STO 0
04	61	x
05	14 02	f $\sqrt{x}$
06	24 02	RCL 2
07	61	x
08	14 74	f PAUSE
09	14 74	f PAUSE
10	14 74	f PAUSE
11	14 74	f PAUSE
12	14 74	f PAUSE
13	24 00	RCL 0
14	21	x ⇄ y
15	25	Σ+
16	74	R/S
17	15 71	g x=o
18	13 20	GTO 20
19	13 01	GTO 01
20	14 21	f $\bar{x}$
21	23 00	STO 0
22	74	R/S
23	14 22	f s
24	74	R/S

DISPLAY		KEY ENTRY
LINE	CODE	
25	24 04	RCL 4
26	24 03	RCL 3
27	71	÷
28	74	R/S
29	00	0
30	23 03	STO 3
31	23 04	STO 4
32	23 05	STO 5
33	23 06	STO 6
34	23 07	STO 7
35	13 00	GTO 00
36	15 02	g x^2
37	05	5
38	73	•
39	00	0
40	07	7
41	02	2
42	33	EEX
43	32	CHS
44	04	4
45	61	x
46	24 00	RCL 0
47	61	x
48	74	R/S
49	13 36	GTO 36

REGISTERS	
R_0	T_i, V_i, $(V_s)_{avg}$
R_1	460
R_2	θ
R_3	i
R_4	ΣT_i
R_5	$\Sigma V_i T_i$
R_6	ΣV_i^2
R_7	ΣV_i

Note: Lines 08 through 12 display point velocities briefly. For shorter display time, replace "f PAUSE" with "g NOP". To hold the display of the point velocity a "R/S" may be used in place of the "f PAUSE" on line 12. Operating instructions should be adjusted accordingly.

APOL-09A

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute Intermediate Values					
	a. Constant values		460	STO	1	
	b. Compute M_d		B_{N_2}	↑		
			B_{CO}	+		
			28	x		
			B_{O_2}	↑		
			32	x	+	
			B_{CO_2}	↑		
			44	x	+	M_d
	c. Compute M_s		(M_d)	↑		
			1	↑		
			B_{wo}	−	x	
			B_{wo}	↑		
			18	x	+	M_s
	d. Compute θ		28.95	↑		
			M_s	+		
			29.92	x		
	$(P_s = P_{bar} \pm \frac{\Delta P_s}{13.6})$		P_s	+		
				f	$\sqrt{x}$	
			2.9	x		
			C_p	x		θ
				STO	2	
4	Compute velocities from pitot data					
	$(\Delta p_i, T_i)$:					
	a. Store constants		(θ)	STO	2	
	b. Compute point velocities					
	(in. H_2O)		Δp_i	↑		
	(in °F)	01	T_i	R/S		$[V_i]$
	Do i = 1, n for n points					i

Note: $\Delta p_i = 0$ is not permitted as a data point. $\Delta p = 0$ signals End of Data and causes automatic branching. For a data point close to zero, use small values such as 10^{-9} rather than zero.

APol-09A (cont)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
	c. Compute $(V_s)_{avg}$ in fps,	17	0.00	R/S		$(V_s)_{avg}$
	σ_v (standard deviation) in fps,	23		R/S		σ_v
	and $(T_s)_{avg}$ in °R	25		R/S		$(T_s)_{avg}$
	d. For a new set of traverse points:					
	• Clear registers	29		R/S		0.00
	• Go to step 4e.					
5	Compute Q_I:		$(V_s)_{avg}$	STO	0	
	After all pitot traverse data has		D_N	GTO		
	been loaded, select a nozzle and			3	6	
	compute the corresponding Q_I'	36		R/S		Q_I
	required for isokinetic sampling.					
	Repeat as necessary with					
	different choices for D_N to					
	obtain an acceptable Q_I					
6	a. Key in program APol-09B for					
	$(\Delta P_{sy}, \Delta H, \Delta H')$ sets					
	or					
	Key in program APol-09C for					
	$(\Delta P_{sy}, \Delta H, t)$ sets					
	[illegible] Proceed to the appropriate set					
	of instructions					

Example No. 1: For Stack Velocities and Nozzle Selection

1. Key in program APol-09A

3b. $B_{N_2} = 0.78$, $B_{CO} = 0.02$, $B_{O_2} = 0.05$, $B_{CO_2} = 0.15$ → $M_d = 30.60$ amu

3c. $B_{wo} = 0.06$ → $M_s = 29.84$ amu

3d. $M_s = 29.84$

$P_{bar} = 29.43$ in. Hg, $\Delta P_s = -6.7$ in. H_2O → $P_s = 28.94$ in. Hg.

$C_p = 0.83$ → $\theta = 2.41$

4b. $(\Delta p_1, T_1)$ = (0.06 in. H_2O, 321°F) → V_1 = 16.50 ft/sec, n = 1
$(\Delta p_2, T_2)$ = (0.08 in. H_2O, 329°F) → V_2 = 19.15 ft/sec, n = 2
$(\Delta p_3, T_3)$ = (0.08 in. H_2O, 330°F) → V_3 = 19.16 ft/sec, n = 3
$(\Delta p_4, T_4)$ = (0.07 in. H_2O, 325°F) → V_4 = 17.87 ft/sec, n = 4

4c. 0 → $(V_s)_{avg}$ = 18.17 ft/sec
→ σ_V = 1.27
→ $(T_s)_{avg}$ = 786.3°R

5. D_N = 1.5 mm → Q_I = 0.0207 ft³/min
D_N = 2.0 mm → Q_I = 0.0369 ft³/min

6. Key in desired program; APol-09B for $(\Delta P_{sy}, \Delta H, \Delta H')$ sets or APol-09C for $(\Delta P_{sy}, \Delta H, t)$ sets.

FOR $(\Delta P_{sy}, \Delta H, \Delta H')$ SETS; TWO ORIFICES

APol-09B

DISPLAY		KEY ENTRY	
LINE	CODE		
00			
01	15 02	g x^2	
02	71	÷	
03	24 05	RCL 5	
04	61	x	
05	74	R/S	
06	13 01	GTO 01	
07	24 04	RCL 4	
08	24 01	RCL 1	
09	24 02	RCL 2	
10	24 03	RCL 3	
11	74	R/S	
12	41	−	
13	71	÷	
14	23 07	STO 7	
15	74	R/S	
16	01	1	
17	03	3	
18	73	·	
19	06	6	
20	71	÷	
21	24 03	RCL 3	
22	51	+	
23	24 02	RCL 2	
24	21	x⇌y	
25	41	−	
26	23 06	STO 6	
27	71	÷	
28	74	R/S	*
29	24 06	RCL 6	
30	71	÷	
31	14 02	f $\sqrt{x}$	
32	24 00	RCL 0	
33	61	x	
34	06	6	**
35	73	·	
36	00	0	
37	00	0	
38	21	x⇌y	
39	71	÷	
40	00	0	***
41	73	·	
42	05	5	
43	00	0	
44	23 51 03	STO + 3	
45	22	R ↓	
46	15 74	g NOP	†
47	13 07	GTO 07	
48	13 00	GTO 00	
49	13 00	GTO 00	

REGISTERS	
R_0	c_o, α
R_1	α
R_2	P_{bar}
R_3	ΔP_{sy}
R_4	c'_o, λ
R_5	β
R_6	P'_o
R_7	ΔH

* R/S displays ΔH'
** Enter value as determined for K from equation 9-4
*** Increment for ΔP_{sy}
† R/S displays t

APol-09B

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute Intermediate Values					
	a. Compute c_c		T_c	↑		
			ΔH_c	×		
			P_c	÷		
			M_c	÷		c_c
				STO	0	
	b. Compute c'_c		T'_c	↑		
			$\Delta H'_c$	×		
			P'_c	÷		
			M'_c	÷		c'_c
				STO	4	
	c. Compute β		Q_l	↑		
			$(T_s)_{avg}$	↑		
			1	↑		
			B_{wo}	−		
			P_s	×	x⇄y	
				÷	x	
				g	x^2	
			M_d	↑		
			T_o	×	×	β
				STO	5	
	d. Compute α			RCL	5	β
				RCL	0	c_c
		01	Q_{cal}	R/S		α
				STO	0	
				STO	1	

APol-09B (cont)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
	e. Compute λ			RCL	5	β
				RCL	4	c'_c
		01	Q'_{cal}	R/S		λ
				STO	4	
4	Compute (ΔP_{sy}, ΔH, $\Delta H'$)					
	a. Store Intermediate Values		P_{bar}	STO	2	
	values		(α)	STO	0	
			(α)	STO	1	
			(λ)	STO	4	
	b. For a specific value		ΔP_{sy}	STO	3	
	of ΔP_{sy}, compute			GTO		
	(ΔP_{sy}, ΔH, $\Delta H'$)			O	7	
		07		R/S		ΔP_{sy}
		12		R/S		ΔH
		16		R/S		$\Delta H'$
	c. To increment previous					
	ΔP_{sy} by Steps of					
	+0.5 in. Hg	07		R/S		New ΔP_{sy}
		12		R/S		ΔH
		16		R/S		$\Delta H'$

Example No. 2: For (ΔP_{sy}, ΔH, $\Delta H'$) Sets; Two Orifices

1. Key in program APol-09B

3a. T_c = 535°R, ΔH_c = 10 in. H_2O, P_c = 29.50 in. Hg,
M_c = 28.97 → c_c = 6.26

3b. T'_c = 535°R, $\Delta H'_c$ = 10 in. H_2O, P'_c = 29.50 inches,
M'_c = 28.97 → c'_c = 6.26

3c. Q_I = 0.0369 ft^3/min, $(T_s)_{avg}$ = 786.3°R, B_{wo} = 0.06, P_s = 28.94 in. Hg,
M_d = 30.60 amu, T_o = 75°F + 460 = 535°R
→ $\beta = 2.67 \times 10^{-2}$

3d. c_c = 6.26, Q_{cal} = 0.02363 ft^3/min → α = 299.13

3e. c'_c = 6.26, Q'_{cal}= 0.02509 ft^3/min → λ = 265.33

4a. P_{bar} = 29.43

4b. ΔP_{sy} = 1.5 in. Hg → ΔH = 10.7 in. H_2O, $\Delta H'$ = 9.8 in. H_2O

	ΔP_{sy}	ΔH	$\Delta H'$
4c.	2.0 in. Hg	10.9 in. H_2O	10.0 in. H_2O
	2.5 in. Hg	11.1 in. H_2O	10.2 in. H_2O
	3.0 in. Hg	11.3 in. H_2O	10.4 in. H_2O
	3.5 in. Hg	11.5 in. H_2O	10.6 in. H_2O

FOR (ΔP_{sy}, ΔH, t) SETS; ORIFICE AND GAS METER

APol-09C

DISPLAY		KEY ENTRY		DISPLAY		KEY ENTRY	
LINE	CODE			LINE	CODE		
00				25	41	−	
01	15 02	g x^2		26	23 06	STO 6	
02	71	÷		27	71	÷	
03	24 05	RCL 5		28	15 74	g NOP	*
04	61	x		29	24 06	RCL 6	
05	74	R/S		30	71	÷	
06	13 01	GTO 01		31	14 02	f $\sqrt{x}$	
07	24 04	RCL 4		32	24 00	RCL 0	
08	24 01	RCL 1		33	61	x	
09	24 02	RCL 2		34	06	6	**
10	24 03	RCL 3		35	73	·	
11	74	R/S		36	00	0	
12	41	−		37	00	0	
13	71	÷		38	21	x⇌y	
14	23 07	STO 7		39	71	÷	
15	74	R/S		40	00	0	***
16	01	1		41	06	·	
17	03	3		42	05	5	
18	73	·		43	00	0	
19	06	6		44	23 51 03	STO + 3	
20	71	÷		45	22	R ↓	
21	24 03	RCL 3		46	74	R/S	†
22	51	+		47	13 07	GTO 07	
23	24 02	RCL 2		48	13 00	GTO 00	
24	21	x⇌y		49	13 00	GTO 00	

REGISTERS	
R_0	ϕ
R_1	c_0, α
R_2	ΔP_{bar}
R_3	ΔP_{sy}
R_4	α
R_5	β
R_6	P'_o
R_7	ΔH

* R/S displays $\Delta H'$

** Enter value as determined for K from equation 9-4

*** Increment for ΔP_{sy}

† R/S displays t

Note: Programs APol-09B and APol-09C are identical except for Lines 28 and 46. To change from APol-09B to APol-09C: RUN mode, GTO 27; PRGM mode, g NOP; RUN mode, GTO 45; PRGM mode, R/S; RUN mode, enter data. To change from Apol-09C back to Apol-09B: RUN mode, GTO 27; PRGM mode, R/S; RUN mode, GTO 45; PRGM mode, g NOP; RUN mode, enter data.

APol-09C

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
	Note:					
	Enter, as program steps, the					
	correct value for K from					
	equation (9-4).					
2	RUN mode: Initialize			f	PRGM	
3	Compute Intermediate Values					
	a. Compute C_c		T_c	↑		
			ΔH_c	×		
			P_c	÷		
			M_c	÷		c_c
				STO	1	
	b. Compute β		Q_l	↑		
			$(T_s)_{avg}$	↑		
			1	↑		
			B_{wo}	−		
			P_s	×	x⇄y	
				÷	×	
				g	x^2	
			M_d	↑		
			T_o	×	×	β
				STO	5	
	c. Compute α			RCL	5	β
				RCL	1	c_c
		01	Q_{cal}	R/S		α
			(α)	STO	1	
			(α)	STO	4	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
	d. Compute ϕ		T_o	↑		
			M_d	÷		
			c_c	÷		
				f	$\sqrt{x}$	
			Q_{cal}	×		ϕ
				STO	0	
4	Compute (ΔP_{sy}, ΔH, t)					
	a. Store Intermediate Values		P_{bar}	STO	2	
			(α)	STO	1	
			(α)	STO	4	
			(ϕ)	STO	0	
	b. For a specific value		ΔP_{sy}	STO	3	
	of ΔP_{sy}, compute			GTO		
	(ΔP_{sy}, ΔH, t)			0	7	
		07		R/S		ΔP_{sy}
		12		R/S		ΔH
		16		R/S		t
	c. To increment previous					
	ΔP_{sy} by steps of					
	+0.5 in. Hg	07		R/S		New ΔP_{sy}
		12		R/S		ΔH
		16		R/S		t

Example No. 3: For (ΔP_{sy}, ΔH, t) Sets; Orifice and Gas Meter

1. Key in program APol-09C

3a. T_c = 535°R, ΔH_c = 10 in. H_2O, P_c = 29.50 in. Hg,
M_c = 28.97 amu → c_c = 6.26

3b. Q_I = 0.5808 ft^3/min, $(T_s)_{avg}$ = 786.3°R, B_{wo} = 0.06, P_s = 28.94 in. Hg,
M_d = 30.60 amu, T_o = 75°F + 460 = 535°R
→ β = 6.61

3c. c_c = 6.26, Q_{cal} = 0.3512 ft^3/min → α = 335

3d. T_o = 535°R, M_d = 30.60 amu, c_c = 6.26, Q_{cal} = 0.3512 ft^3/min
→ ϕ = 0.587

4a. P_{bar} = 29.43 in. Hg

4b.	ΔP_{sy} = 1.5 in. Hg	→	ΔH = 12.0 in. H_2O, t =	15.1 sec
4c.	ΔP_{sy} = 2.0 in. Hg		ΔH = 12.2 in. H_2O, t =	14.8 sec
	2.5 in. Hg		12.5 in. H_2O	14.5 sec
	3.0 in. Hg		12.7 in. H_2O	14.2 sec
	3.5 in. Hg		12.9 in. H_2O	13.9 sec

STACK VELOCITIES AND NOZZLE SELECTION

HP 25 APol-09A

Format

Δp_i	T_i
V_i	

Velocity Traverse - Inlet/Outlet (Circle One)

Plant: ____________________ Date ____________

Location: ____________________ Time (Circle One) AM / PM

POINT VELOCITIES

Depth = ____________

(Top)

Port Number

Traverse Point No.	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

(Bottom)

0

$(V_s)_{avg}$ = ____________ fps, σ_V = ____________ fps

$(T_s)_{avg}$ = ____________ °R

D_N = ____________ mm

GTO 36

R/S → Q_I = ____________ CFM

D_N = ____________ mm

R/S → Q_I = ____________ CFM

INCHES		INCHES		MM
1/8	=	.125	=	3.18
3/16	=	.1875	=	4.76
1/4	=	.250	=	6.35
5/16	=	.3125	=	7.94
3/8	=	.375	=	9.53
1/2	=	.500	=	12.70

INTERMEDIATE VALUES

460

(STO 1)

28.95

B_{N_2} = ________________

B_{CO} = ________________

28

B_{O_2} = ________________

32

B_{CO_2} = ________________

44

→ M_d = ________________

1.00

B_{wo} = ________________

B_{wo} = ________________

18

→ M_s = ________________

28.95

M_s = ________________

29.92

P_{bar} = ________________ in. Hg ±ΔP_s = ________________ in. H_2O 13.6

→P_s = ________________ in. Hg

2.9

C_p = ________________

θ = ________________________ (2.5)

(STO 2)

(over)

CASCADE IMPACTOR OPERATION
HP-25 APol-09B

For (ΔP_{sy}, ΔH, $\Delta H'$) Sets; Two Orifices

Inlet/Outlet (Circle One)

Plant: ______ Date. ______
Location: ______ Time (Circle One) AM / PM

Orifice No. 1

ID:
Q_{cal}: ______ CFM
T_c = ______ °R
ΔH_c = ______ in. H_2O
P_c = ______ in. Hg
M_c = ______ amu
c_c = ______

Orifice No. 2

ID:
Q'_{cal}: ______ CFM
T'_c = ______ °R
$\Delta H'_c$ = ______ in. H_2O
P'_c = ______ in. Hg
M'_c = ______ amu
c'_c = ______

Compute β

Q_I = ______ CFM
$(T_s)_{avg}$ = ______ °R
1.0
B_{wo} = ______
P_s = ______ in. Hg
M_d = ______
T_o = ______ °F + 460 = ______ °R
β = ______ (STO 5)

Compute α

c_c = ______
Q_{cal} = ______ CFM
α = ______ (STO 0 & 1)

Compute λ

c'_c = ______
Q'_{cal} = ______ CFM
λ = ______ (STO 3)

Compute (ΔP_{sy}, ΔH, $\Delta H'$)

P_{bar} = ______ in. Hg (STO 2)
α = ______ (STO 0 & 1)
λ = ______ (STO 4) ΔP_{sy}STO 3

ΔP_{sy} (in. Hg)	No. 1 ΔH (in. H_2O)	No. 2 $\Delta' H$ (in. H_2O)	ΔP_{sy}	ΔH	$\Delta H'$	ΔP_{sy}	ΔH	$\Delta H'$

CASCADE IMPACTOR OPERATION

HP 25 **APol-09C**

For (ΔP_{sy}, ΔH, t) Sets; Orifice and Gas Meter

Inlet/Outlet (Circle One)

Plant: ______________________ Date: ______________________

Location: ______________________ Time (Circle One) AM / PM

Orifice

ID:

Q_{cal}: ______________ CFM

T_c = ______________ °R

ΔH_c = ______________ in. H_2O

P_c = ______________ in. Hg

M_c = ______________ amu

→ c_c = ______________

Compute β

Q_I = ______________ CFM

$(T_s)_{avg}$ = ______________ °R

1.0

B_{wo} = ______________

P_s = ______________ in. Hg

M_d = ______________

T_o = ______________ °F + 460 = ______________ °R

→ β = ______________ (STO 5)

Compute α

c_c = ______________

Q_{cal} = ______________ CFM

→ α = ______________ (STO 1 & 4)

Compute ϕ

T_o = ______________ °R

M_d = ______________ amu

c_c = ______________

Q_{cal} = ______________ CFM

→ ϕ = ______________ (STO 0)

Compute (ΔP_{sy}, ΔH, $\Delta H'$)

P_{bar} = ______________ in. Hg (STO 2)

α = ______________ (STO 1 & 4)

ϕ = ______________ (STO 0)

ΔP_{sy} STO 3

ΔP_{sy} (in. Hg)	ΔH (in. H_2O)	t (sec)	ΔP_{sy}	ΔH	t	ΔP_{sy}	ΔH	t

IMPACTOR FLOW RATE GIVEN ORIFICE ΔH

The actual flow rate through an impactor, Q_I, is given by:

$$Q_I = \frac{Q_{cal}\,T_s}{(1-B_{wo})P_s}\sqrt{\frac{(P_{bar}-\Delta P_{sy})\,\Delta H}{T_o\,M_d\,c_c}} \qquad (10\text{-}1)$$

where

T_s = stack temperature, °R

B_{wo} = volumetric fraction of water

P_{bar} = ambient pressure, in. Hg

ΔP_{sy} = ambient to system pressure differential at a point immediately upstream of the orifice, in. Hg

ΔH = pressure drop across the orifice, in. H_2O

T_o = orifice temperature, °R

c_c = orifice calibration factor given by:

$$c_c = \frac{T_c\ \Delta H_c}{P_c\ M_c} \qquad (10\text{-}2)$$

where

P_c = calibration pressure, in. Hg

T_c = calibration temperature, °R

ΔH_c = pressure drop across the orifice, in. Hg, (at temperature T_c and pressure P_c) when the calibration flow rate Q_c is measured

M_c = mean molecular weight of the calibration gas

Q_{cal} = calibration flow rate for a pressure drop ΔH_c (at conditions T_c and P_c), ft^3/min, actual (i.e., ACFM)

P_s = stack pressure, in. Hg, given by:

$$P_s = P_{bar} + \Delta P_s/13.6$$

where

ΔP_s = pressure differential, ambient to stack, inches H_2O

P_{bar} = ambient pressure, inches Hg

M_d = dry mean molecular weight of the flue gas as given by:

$$M_d = 32\,B_{O_2} + 44\,B_{CO_2} + 28(B_{N_2} + B_{CO})$$

where

B_{N_2}, B_{O_2}, B_{CO_2}, and B_{CO} are the dry volumetric fractions for N_2, O_2, CO_2, and CO respectively.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 03	RCL 3
02	21	x⇌y
03	41	−
04	61	x
05	24 02	RCL 2
06	71	÷
07	14 02	f $\sqrt{x}$
08	24 04	RCL 4
09	61	x
10	24 01	RCL 1
11	61	x
12	01	1
13	24 05	RCL 5
14	41	−
15	71	÷
16	13 00	GTO 00
17	13 00	GTO 00
18	13 00	GTO 00
19	13 00	GTO 00
20	13 00	GTO 00
21	13 00	GTO 00
22	13 00	GTO 00
23	13 00	GTO 00
24	13 00	GTO 00

DISPLAY		KEY ENTRY
LINE	CODE	
25	13 00	GTO 00
26	13 00	GTO 00
27	13 00	GTO 00
28	13 00	GTO 00
29	13 00	GTO 00
30	13 00	GTO 00
31	13 00	GTO 00
32	13 00	GTO 00
33	13 00	GTO 00
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	28.32
R_1	Q_{cal}
R_2	$(M_d \cdot T_o \cdot c_c)$
R_3	P_{bar}
R_4	T_s/P_s
R_5	B_{wo}
R_6	
R_7	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute Q_l					
	a. Store variables		Q_{cal}	STO	1	
			B_{O_2}	↑		
			32	x		
			B_{CO_2}	↑		
			44	x	+	
			B_{N_2}	↑		
			B_{CO}	+		
			28	x	+	M_d

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
	(°F)		T_o	↑		
			460	+	×	
	(equation 10-2)		c_c	×		$M_d \cdot T_o \cdot c_c$
				STO	2	
	(°F)		T_s	↑		
			460	+		
			P_{bar}	STO	3	
	(negative for negative duct pressure)		ΔP_s	↑		
			13.6	÷	+	P_s
				÷		T_s/P_s
				STO	4	
			B_{wo}	STO	5	
	b. Compute Q_I; ACFM	01				
	(in. H_2O)		ΔH	↑		
	(in. Hg)		ΔP_{sy}	R/S		Q_I
4	For a second set (ΔH, ΔP_{sy})					
	using the same orifice, repeat					
	Step 3b above.					
5	For a second set (ΔH, ΔP_{sy})					
	using a different orifice, store					
	the new Q_C in register No. 1					
	then go to Step No. 3b above.					
6	Convert CFM → LPM					
	a. Store		28.32	STO	0	
	b. Convert		CFM	RCL	0	
				×		LPM

Example:

Q_{cal} = 0.420 CFM
B_{O_2} = 0.06
32
B_{CO_2} = 0.13
44
B_{N_2} = 0.78
B_{CO} = 0.03
28

→ M_d = 30.32 amu

T_o = 45°F
460
c_c = 6.260

(for P_c = 29.50 in. Hg, T_c = 535°R
ΔH_c = 10 in. H_2O, M_c = 28.97)

T_s = 380°F
460
P_{bar} = 28.04 in. Hg
ΔP_s = −6.0 in H_2O
13.6
B_{wo} = 0.12

ΔH = 6.0 in. H_2O
ΔP_{sy} = 2.0 in. Hg

→ Q_I = 0.586 ACFM (stack conditions)
(= 16.6 ALPM, stack conditions)

ΔH = 6.5 in. H_2O
ΔP_{sy} = 4.0 in. Hg

→ Q_I = 0.587 ACFM (stack conditions)
(= 16.6 ALPM, stack conditions)

Q_{cal} = 0.0494 CFM
ΔH = 1.4 in. H_2O
ΔP_{sy} = 2.0 in. Hg

→ Q_I = 0.0333 ACFM (stack conditions)
(= 0.944 ALPM, stack conditions)

IMPACTOR FLOW RATE GIVEN GAS VELOCITY AND NOZZLE DIAMETER

For isokinetic sampling, when the average flue gas velocity (or point velocity if a single point sample is taken) over a traverse path is known, the actual flow rate through an impactor (Q_I) corresponding to a given choice of nozzle diameter, D_N, is given by:

$$Q_I = 5.072 \times 10^{-4}(V_s)_{avg}(D_N)^2 \qquad (11\text{-}1)$$

where

Q_I = actual flow rate through the impactor, ft³/min (i.e., ACFM)
$(V_s)_{avg}$ = average flue gas velocity, feet per second
D_N = nozzle diameter, millimeters

For Q_I in cm³/sec:

$$Q_I = 0.2394\,(V_s)_{avg}(D_N)^2 \qquad (11\text{-}2)$$

For Q_I in liters per minute (LPM):

$$Q_I = 0.01436\,(V_s)_{avg}(D_N)^2 \qquad (11\text{-}3)$$

(All Q_I are for actual temperature and pressure)

Note:
- 1/4 inch = 6.35 mm
- 3/8 inch = 9.53 mm
- 1/2 inch = 12.7 mm
- 1.00 inch = 25.4 mm
- 1.00 mm = 0.0394 inch

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 01	RCL 1
02	24 02	RCL 2
03	61	x
04	24 02	RCL 2
05	61	x
06	23 03	STO 3
07	05	5
08	00	0
09	07	7
10	02	2
11	33	EEX
12	32	CHS
13	07	7
14	61	x
15	74	R/S
16	24 03	RCL 3
17	73	.
18	02	2
19	03	3
20	09	9
21	04	4
22	61	x
23	74	R/S
24	24 03	RCL 3

DISPLAY		KEY ENTRY
LINE	CODE	
[illegible]	73	.
26	00	0
27	01	1
28	04	4
29	03	3
30	06	6
31	61	x
32	13 00	GTO 00
33	13 00	GTO 00
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	
R_1	$(V_s)_{avg}$
R_2	D_N
R_3	(work)
R_4	
R_5	
R_6	
R_7	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: initialize			f	PRGM	
3	a. Store variables (ft/sec)		$(V_s)_{avg}$	STO	1	
	(mm)		D_N	STO	2	
	b. Compute Q_I, ft^3/min	01		R/S		Q_I
	c. Compute Q_I, cm^3/sec	16		R/S		Q_I
	d. Compute Q_I, liters/min	24		R/S		Q_I

Example:

$(V_s)_{avg}$ = 60 ft/sec

D_N = 2 mm

→ Q_I = 0.1217 ACFM

Q_I = 57.46 cm^3/sec, actual

Q_I = 3.446 ALPM

IMPACTOR SAMPLING TIME TO COLLECT 50 MILLIGRAMS

The approximate time (t_g) required to collect 50 mg of sample for a mass loading in units of grains per actual cubic feet is given by:

$$t_g = \frac{0.77162}{(Q_I)\ (G)} \qquad (12\text{-}1)$$

where

t_g = collection time, minutes
Q_I = actual impactor flow rate, ACFM
G = mass loading, gr/ACF

If the mass loading is given in units of milligrams per actual cubic meter, the approximate time is given by:

$$t'_g = \frac{1765.7}{(Q_I)\ (G')} \qquad (12\text{-}2)$$

where

Q_I = actual impactor flow rate, ACFM
G' = mass loading, mg/ACM

Note:
- 1.00 lb = 7,000 grains
- 1.00 lb = 453.6 grams

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 03	RCL 3
02	24 01	RCL 1
03	71	÷
04	24 02	RCL 2
05	71	÷
06	15 74	g NOP •
07	06	6
08	00	0
09	71	÷
10	14 11 04	f FIX 4
11	14 00	f → H.MS
12	13 00	GTO 00
13	13 00	GTO 00
14	13 00	GTO 00
15	13 00	GTO 00
16	13 00	GTO 00
17	13 00	GTO 00
18	13 00	GTO 00
19	13 00	GTO 00
20	13 00	GTO 00
21	13 00	GTO 00
22	13 00	GTO 00
23	13 00	GTO 00
24	13 00	GTO 00
25	13 00	GTO 00
26	13 00	GTO 00
27	13 00	GTO 00
28	13 00	GTO 00
29	13 00	GTO 00
30	13 00	GTO 00
31	13 00	GTO 00
32	13 00	GTO 00
33	13 00	GTO 00
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	
R_1	G or G'
R_2	Q_I
R_3	**
R_4	
R_5	
R_6	
R_7	

* Optional R/S
** 0.77162 or 1765.7

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute t_g, given the grain loading					
	a. Store variables					
	(grains/ACF)		G	STO	1	
	(ACFM)		Q_I	STO	2	
			0.77162	STO	3	
	b. Compute t_g	01		R/S		t_g
	(Note: Output is in the format					
	HH.MMSS; i.e., hours, minutes,					
	seconds. Insert optional R/S					
	for output in decimal minutes.)					
4	Compute t'_g, given the mg loading					
	a. Store variables					
	(mg/ACM)		G'	STO	1	
	(ACFM)		Q_I	STO	2	
			1765.7	STO	3	
	b. Compute t'_g	01		R/S		R/S
	(Note: Same output format as 3b.)					
5	Convert lbs → grains					
	a. Store		7,000	STO	0	
	b. RCL		lbs	RCL	0	
				x		grains

Example:

For mass loading in units of gr/ACF:

$G = 2$ gr/ACF
$Q_I = 0.03$ ACFM
0.77162

→ $t_g = 0.1252$
(i.e., 12 min, 52 sec)
(w/opt. R/S: 12.86 minutes)

$G = 0.006$ gr/ACF
$Q_I = 0.50$ ACFM
0.77162

→ $t_g = 4.1712$
(i.e., 4 hours, 17 min, 12 sec)
(w/opt. R/S: 257.2 min)

For mass loading in units of mg/ACM:

$G' = 13$ mg/ACM
$Q_I = 0.5$ ACFM
1765.7

→ t'_g 4.3139
(i.e., 4 hours, 31 min, 39 sec)
(w/opt. R/S: 271.6 min)

IMPACTOR FLOW RATE, SAMPLE VOLUME, MASS LOADING

The average flow rate through the gas meter (Q_m), at meter conditions is given by:

$$Q_m = V_m/t$$

where

Q_m = average flow rate through the gas meter, meter conditions, ft^3/min, (i.e., ACFM)
V_m = measured volume, ft^3
t = run time, minutes

The average actual flow rate through the impactor, $(Q_I)_{avg}$, stack conditions, is given by:

$$(Q_I)_{avg} = Q_m \left[\frac{(P_{bar} - \Delta P_m)}{P_s}\right]\left[\frac{T_s}{T_m \ (1 - B_{wo})}\right] \qquad (13\text{-}1)$$

where

$(Q_I)_{avg}$ = average actual flow rate through the impactor, as determined by the gas meter measurement, stack conditions, ft^3/min
P_{bar} = ambient pressure, absolute, in. Hg
P_s = stack pressure, absolute given by $P_s = P_{bar} + \Delta P_s/13.6$ where ΔP_s is the stack to ambient pressure differential, in. H_2O
T_s = temperature of the stack gas, absolute, °R
T_m = temperature of the metered gas, °R
B_{wo} = volumetric fraction of water, dimensionless
ΔP_m = meter to ambient pressure differential, in. Hg, at the inlet to the gas meter given by:

$$\Delta P_m = \Delta P_{sy} + (\Delta H/13.6)$$

where

ΔP_{sy} = ambient to system pressure differential at a point immediately upstream of the orifice, inches Hg
ΔH = pressure drop across the orifice, inches H_2O

(Note: The above equation for ΔP_m is for an equipment set-up such that the gas meter is immediately downstream from the orifice.)

Correspondingly, the actual volume, $(V_I)_{avg}$ through the impactor (sample volume) at stack conditions is given by:

$$(V_I)_{avg} = (Q_I)_{avg} \times t \tag{13-2}$$

where

$(V_I)_{avg}$ = average actual volume through the impactor, stack conditions, ft^3
t = run time, minutes
$(Q_I)_{avg}$ is defined by equation (13-1).

This impactor sample volume corrected to normal conditions (68°F, 29.92 in. Hg) is given by:

$$V_N = (V_I)_{avg} \left[17.65 \frac{P_s}{T_s} (1 - B_{wo})\right] \tag{13-3}$$

where

V_N = $(V_I)_{avg}$ corrected to normal conditions, dry, ft^3
$(V_I)_{avg}$, P_s, T_s, and B_{wo} are as defined above.

Thus the Mass Loading (G_N), normal conditions, is given by:

$$G_N = (0.01543)\ M_s/V_N \tag{13-4}$$

where

G_N = mass loading, normal conditions, dry, grains/ft^3 (i.e., gr/DNCF)
M_s = mass collected on a given stage when stage loadings are desired; or M_s is the total mass collected for all stages (plus backup filter) when the total mass loading is desired, grains
V_N is as defined above.

This same mass loading expressed in terms of stack conditions (wet) is given by:

$$G_A = (0.01543)\ M_s/(V_I)_{avg} \tag{13-5}$$

where

G_A = mass loading, stack conditions, wet, grains/actual ft^3 (i.e., gr/ACF)
$(V_I)_{avg}$ and M_s are as defined above.

Note: 1 gr/ft^3 = 2.288 gm/m^3

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 04	RCL 4
02	71	÷
03	74	R/S
04	71	÷
05	51	+
06	24 01	RCL 1
07	21	x⇌y
08	41	–
09	61	x
10	24 03	RCL 3
11	71	÷
12	24 02	RCL 2
13	71	÷
14	74	R/S
15	24 04	RCL 4
16	61	x
17	23 07	STO 7
18	74	R/S
19	61	x
20	24 02	RCL 2
21	61	x
22	23 06	STO 6
23	74	R/S
24	23 00	STO 0

DISPLAY		KEY ENTRY
LINE	CODE	
25	24 06	RCL 6
26	71	÷
27	24 05	RCL 5
28	61	x
29	74	R/S
30	24 00	RCL 0
31	24 05	RCL 5
32	61	x
33	24 07	RCL 7
34	71	÷
35	74	R/S
36	13 24	GTO 24
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	M_s
R_1	P_{bar}
R_2	*
R_3	T_m
R_4	t
R_5	0.01543
R_6	V_n
R_7	$(V_l)_{avg}$

* $(1\text{-}B_{wo})P_s/T_s$

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute Q's and V's					
	a. Store variables		P_{bar}	STO	1	
	(Negative for negative duct)		ΔP_s	↑		
			13.6	÷	+	P_s
	(°F)		T_s	↑		
			460	+	÷	
			1	↑		
			B_{wo}	−	x	$(1-B_{wo})P_s/T_s$
				STO	2	
	(°F)		T_m	↑		
			460	+		
				STO	3	
			t	STO	4	
	b. Compute Q_m	01	V_m	R/S		Q_m
	c. Compute $(Q_I)_{avg}$	04	ΔP_{sy}	↑		
			ΔH	↑		
			13.6	R/S		$(Q_I)_{avg}$
	d. Compute $(V_I)_{avg}$	15		R/S		$(V_I)_{avg}$
	e. Compute V_N	19	17.71	R/S		V_N
4	Compute G_N & G_A					
	a. Store		0.01543	STO	5	
			(V_N)	STO	6	
			$((V_I)_{avg})$	STO	7	
	b. Compute G_N	24	M_s	R/S		G_N
	c. Compute G_A	30		R/S		G_A
	d. For new Stage weights					
	repeat Steps 4b. and 4c.					
5	Convert gr/ft³ → gm/m³		gr/ft³	↑		
			2.288	x		gm/m³

Example:

P_{bar} = 30.00 in Hg
ΔP_s = −13.6 in H_2O
13.6

→ P_s = 29.00 in Hg

T_s = 300°F
460
1
B_{WO} = 0.05
T_m = 70°F
460
t = 20 min
V_m = 10 ft^3

→ Q_m = 0.50 ACFM (meter conditions)

ΔP_{sy} = 1.6 in. Hg
ΔH = 5.4 in H_2O
13.6

→ $(Q_I)_{avg}$ = 0.73 ACFM (stack conditions)
$(V_I)_{avg}$ = 14.58 ACF (stack conditions)

17.71

→ V_N = 9.36 DNCF (normal conditions)

0.01543

For Stage One: M_1 = 25 mg → Stage One Mass Loadings are:

G_N = 0.041 gr/DNCF (= 0.094 gm/DNCM)
G_A = 0.026 gr/ACF (= 0.061 gm/ACM)

⋮

For Total Stage weight:

M_T = 100 mg → Total Mass Loading is:

G_N = 0.16 gr/DNCF (= 0.38 gm/DNCM)
G_A = 0.11 gr/ACF (= 0.24 gm/ACM)

IMPACTOR STAGE D_{50}

For a given geometry, the impactor stage D_{50} cutpoints are determined by the conditions at which the impactor is run. The stage D_{50}'s can be calculated by an iterative solution of the following two equations (14-1) and (14-2):

$$\#S{:}D_{50_i} = K_s \sqrt{\frac{\mu \, P_s}{(Q \ \rho_p \ P_A) \, C_{i-1}}} \tag{14-1}$$

where

$\#S{:}D_{50_i}$ = the i^{th} iteration for the D_{50} for Stage #S, cm

K_s = the stage constant, a function of geometry, (see also Tables (14-1) through (14-5) and equations (14-5)and (14-6))

P_s = local absolute pressure downstream of the stage jet, inches Hg

Q = impactor flow rate, cm^3/sec

P_A = absolute pressure at impactor inlet, inches Hg

ρ_p = particle density, gm/cm^3

μ = gas viscosity, gm/cm-sec given by:*

$$\mu = (174.4 + 0.406 \ T) \times 10^{-6}$$

where

T = gas temperature, °C

C_{i-1} = slip correction factor, i−1 iteration

An initial guess, C_o, is used for D_{50_1}; subsequent C_i, using D_{50_i}, are given by:

$$C_i = 1 + \frac{2L}{D_{50_i}} \left[1.23 + 0.41 \ \mathrm{EXP} \left(-.44 \ \frac{D_{50_i}}{L}\right) \right] \tag{14-2}$$

where

D_{50_i} = $\#S{:}D_{50_i}$ given by equation (14-1) using the previously calculated value for C_{i-1} (for $i \neq 1$ and C_o for $i = 1$)

L = mean free path of the gas, cm, given by:*

$$L = 1.04 \ \frac{\mu}{P_s} \sqrt{1 + 0.00367T} \tag{14-3}$$

where

μ, P_s, and T are the same as in equation (14-1) and T has units of °C.

* For Standard Air only, 0° to 410°C; maximum error, 2%.

An initial value, C_o, is chosen for use in equation (14-1) for $i = 1$, then subsequent calculations for D_{50i} use C_{i-1}. A closeness criterion is used to determine when D_{50i} has adequately approached the D_{50}. This criterion is satisfied when:

$$\left| 1 - \frac{C_{i-1}}{C_i} \right| \leq 0.001 \qquad (14\text{-}4)$$

The impactor stage constant K_s is a function of geometry. For round holes, K_{sRO} is given by:

$$K_{sRO} = \sqrt{\Psi_{50_s}} \left(\frac{18\pi \, D_s^3 \, X_s}{4} \right)^{1/2} \qquad (14\text{-}5)$$

where

$\sqrt{\Psi_{50_s}}$ = square root of the Stokes number at 50% collection efficiency (theoretical, or from calibration data), for stage s, dimensionless[1]

X_s = number of jets per stage

D_s = jet diameter, cm

The impactor stage constant for rectangular slits is given by:

$$K_{sRT} = \sqrt{\Psi_{50_s}} \; (18 \, w^2 L)^{1/2} \qquad (14\text{-}6)$$

where

$\sqrt{\Psi_{50_s}}$ = square root of the Stokes number at 50% collection efficiency (theoretical, or from calibration data) for stage s, dimensionless

w = width of slit

L = total length of slit or slits on stage s

Note:

- Tables 14-1 through 14-5 give tabulated typical stage constants, K_s, for five commercially available cascade impactors. These values were obtained by using equation (14-5), or (14-6) and the calibration values of $\sqrt{\Psi_{50_s}}$ for each stage. When a different geometry is used the value for $\sqrt{\Psi_{50_s}}$ should be recalibrated for the new geometry.
- $1.00\ \mu m = 10^{-4}$ cm
- Aerodynamic diameter stage cut point as defined by the Task Group on Lung Dynamics[2] is calculated by setting the particle density in equation 14-1 equal to unity.
- Impaction aerodynamic diameter stage cut points as defined by Mercer and Stafford[3] are calculated by setting the slip correction factor and particle density both equal to unity in equation 14-1. Calculation of these diameters cannot be made using this program (APol-14).

Reference: 1. Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particle Sizing Techniques for Control Device Evaluation. Environmental Protection Agency. Southern Research Institute. Washington, D. C. Environmental Protection Tech. Series No. EPA-600/2-76-280. 1976. p. 94.

2. Task Group on Lung Dynamics, "Deposition and Retention Models for Internal Dosemetry of the Human Respiratory Tract", Health Physics, Vol. 12. 1966. pp. 173-203.

3. Mercer, T.T., Stafford, R.G. "Impaction from Round Jets". Ann. Occupational Hygiene. Vol. 12. 1969. pp. 41-48.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	01	1
02	51	+
03	14 02	f $\sqrt{x}$
04	21	$x \rightleftharpoons y$
05	71	÷
06	61	x
07	24 07	RCL 7
08	61	x
09	23 01	STO 1
10	24 03	RCL 3
11	24 05	RCL 5
12	24 02	RCL 2
13	61	x
14	14 02	f $\sqrt{x}$
15	71	÷
16	23 06	STO 6
17	24 01	RCL 1
18	71	÷
19	24 04	RCL 4
20	61	x
21	15 07	g e^x
22	73	•
23	04	4
24	01	1
25	61	x
26	24 00	RCL 0
27	51	+
28	02	2
29	61	x
30	24 01	RCL 1
31	61	x
32	24 06	RCL 6
33	71	÷
34	01	1
35	51	+
36	24 02	RCL 2
37	21	$x \rightleftharpoons y$
38	23 02	STO 2
39	71	÷
40	01	1
41	41	−
42	15 03	g ABS
43	73	•
44	00	0
45	00	0
46	01	1
47	14 41	f $x < Y$
48	13 10	GTO 10
49	24 06	RCL 6

REGISTERS	
R_0	1.23
R_1	L
R_2	C_l
R_3	$K_s\sqrt{\mu P_s}$
R_4	−.44
R_5	$(Q \cdot \rho_p \cdot P_A)$
R_6	D_{50_l}
R_7	μ

Using Standard Air as the carrier gas: (μ and L are automatically calculated)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute #I:D_{50}					
	a. Store variables		1.23	STO	0	
			1.50	STO	2	
			-0.44	STO	4	
			Q	↑		
			P_A	×		
			ρ_p	×		
				STO	5	
			174.4	↑		
			0.406	↑		
	(°C)		T	×	+	
				EEX	CHS	
				6	×	
				STO	7	
	b. Compute #I:$_{50}$		K_s	↑		
			P_s	RCL	7	
				×		
				f	$\sqrt{x}$	
				×		
				STO	3	$K_s\sqrt{\mu P_s}$
	(Do I = 1 → N)		1.04	↑		
	Note: Step 3a need only be done		P_s	↑		
	for I = 1		0.00367	↑		
	(°C)		T	×		
	(cm)			R/S		#I:D_{50}
				EEX	4	
	(μm)			×		#I:D_{50}

Example No. 1: Using Standard Air as the carrier gas;
(μ and L are automatically calculated)

Store:

1.23

1.50

$-$ 0.44

$Q = 236\ \text{cm}^3/\text{sec}$

$P_A = 30.00$ in Hg

$\rho_p = 1.35\ \text{gm/cm}^3$

174.4

0.406

$T = 22^\circ\text{C}$

10^{-6}

For Stage 1:

$K_1 = 1.208$

$P_1 = 30.00$ in. Hg

RCL 7

1.04

$P_1 = 30.00$ in Hg

0.00367

$T = 22^\circ\text{C}$

→ $\#1{:}D_{50} = 9.08 \times 10^{-4}$ cm
$= 9.08\ \mu\text{m}$

For Stage 2:

$K_2 = 1.074$

$P_2 = 30.00$ in Hg

RCL 7

1.04

$P_2 = 30.00$ in. Hg

0.00367

$T = 22^\circ\text{C}$

→ $\#2{:}D_{50} = 8.07 \times 10^{-4}$ cm
$= 8.07\ \mu\text{m}$

⋮

For Stage 8:

$K_8 = 0.0544$
$P_8 = 28.50$ in. Hg
RCL 7
1.04
$P_8 = 28.50$ in. Hg
0.00367
$T = 22°C$

$$\rightarrow \quad \#8{:}D_{50} = 3.23 \times 10^{-5} \text{ cm} = 0.323\ \mu\text{m}$$

Using carrier gases other than Standard Air: (μ and L are entered manually)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute $\#i{:}D_{50}$					
	a. Store variables		1.23	STO	0	
			1.50	STO	2	
			-0.44	STO	4	
			Q	↑		
			P_A	×		
			ρ_p	×		
				STO	5	
			μ	STO	7	
			L	STO	1	
	b. Compute $\#i{:}D_{50}$		K_s	↑		
			P_s	RCL	7	
				×		
				f	$\sqrt{x}$	
				×		
	(Do i = 1 → N)			STO	3	$K_s\sqrt{\mu P_s}$
	Note: Step 3a need only be done			GTO		
	for i = 1			1	0	
	cm			R/S		$\#i{:}D_{50}$
				EEX	4	
	μm			×		$\#i{:}D_{50}$

Example No. 2: **Using carrier gases other than Standard Air:**
(μ and L are entered manually)

1.23
1.50
-0.44

$Q = 236\ \text{cm}^3/\text{sec}$
$P_A = 30$ in. Hg
$\rho_p = 1.35\ \text{gm/cm}^3$
$\mu = 9.15 \times 10^{-5}$ gm/sec-cm
$L = 3.40 \times 10^{-6}$ cm

For Stage 1:
$K_1 = 1.208$
$P_1 = 30.00$ in Hg
RCL 7

→ #1:$D_{50} = 6.43 \times 10^{-4}$ cm
$= 6.43\ \mu\text{m}$

For Stage 2:
$K_2 = 1.074$
$P_2 = 30.00$ in Hg
RCL 7

→ #2:$D_{50} = 5.71 \times 10^{-4}$ cm
$= 5.71\ \mu\text{m}$

⋮

For Stage 8:
$K_8 = 0.0544$
$P_8 = 28.50$ in. Hg
RCL 7

→ #8:$D_{50} = 2.45 \times 10^{-5}$ cm
$= 0.245\ \mu\text{m}$

Andersen Mark III Stack Sampler
Andersen 2000, Inc.
Atlanta, Georgia 30320

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$	K_s
1	264	.1638	.311	1.26
2	264	.1253	.431	1.165
3	264	.0948	.411	0.731
4	264	.0759	.391	0.498
5	264	.0567	.330	0.272
6	264	.0359	.370	0.154
7	264	.0261	.330	0.0850
8	156	.0251	.280	0.0523

Table 14-1

Modified Brink Model BMS-11 Cascade Impactor
Monsanto Enviro-Chem Systems, Inc.
St. Louis, Missouri 63166

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$ Glass Fiber	K_s Glass Fiber	$\sqrt{\Psi_{50}}$ Grease	K_s Grease
0	1	.360	.30	.244	.32	.260
1	1	.244	.32	.145	.35	.159
2	1	.176	.27	.0750	.38	.106
3	1	.138	.29	.0559	.34	.0655
4	1	.093	.38	.0405	.26	.0277
5	1	.073	.41	.0304	.33	.0245
6	1	.057	.27	.0138	.27	.0138

Table 14-2

University of Washington Source Test Cascade Impactor
Pollution Control Systems, Inc.
Renton, Washington 98055

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$	K_s
1	1	1.824	.12	1.11
2	6	.577	.31	1.25
3	12	.250	.29	0.472
4	90	.0808	.21	0.172
5	110	.0524	.37	0.175
6	110	.0333	.35	0.0839
7	90	.0245	.30	0.0410

Table 14-3

MRI Model 1502 Inertial Cascade Impactor
Meterology Research, Inc.
Altadena, California 91001

Stage No.	No. of Jets	Jet Diameter (cm)	$\sqrt{\Psi_{50}}$	K_s
1	8	.870	.11	0.949
2	12	.476	.25	1.07
3	24	.205	.35	0.598
4	24	.118	.34	0.254
5	24	.084	.29	0.130
6	24	.052	.35	0.0764
7	12	.052	.40	0.0618

Table 14-4

Sierra Model 226 Source Sampler
Sierra Instruments, Inc.
Carmel Valley, California 93924

Stage No.	Jet Slit Width (cm)	Jet Slit Length (cm)	$\sqrt{\Psi_{50}}$	K_S
1	.359	5.156	.33	1.14
2	.199	5.152	.42	0.805
3	.115	3.882	.65	0.625
4	.063	3.844	.49	0.257
5	.036	3.869	.42	0.126
6	.029	2.301	.43	0.0803

Table 14-5

$\sqrt{\Psi}$ CALCULATION - ROUND JETS

The square root of the Stokes number, $\sqrt{\Psi}$, for an impactor stage is a function of geometry and particle size. For a round hole geometry, this number is given by:

$$\sqrt{\Psi_j} = D_{pj} \sqrt{\frac{7.07 \times 10^{-2} \; (Q \, \rho_p \; P_A) \; C_j}{\mu P_s \; (D_c{}^3 X)}} \qquad (15\text{-}1)$$

where

$\sqrt{\Psi_j}$ = square root of the Stokes number for this stage for a particle having diameter D_{pj}, dimensionless
D_{pj} = particle diameter (note: spherical particles are assumed), cm
P_s = local absolute pressure downstream of the stage jet, inches Hg
Q = impactor flow rate, cm³/sec
P_A = absolute pressure at impactor inlet, inches Hg
ρ_p = particle density, gm/cm³
D_c = jet diameter, cm
X = number of jets for this stage
7.07×10^{-2} = $4/18\pi$, a constant
μ = gas viscosity, gm/sec-cm, given by:*

$$\mu = (174.4 + 0.406\ T) \times 10^{-6}$$

where

T = gas temperature, °C
C_j = slip correction factor for this particle diameter is given by:

$$C_j = 1 + \frac{2L}{D_{pj}} \left[1.23 + 0.41 \ \mathrm{EXP} \ \left(-.44 \ \frac{D_{pj}}{L} \right) \right] \qquad (15\text{-}2)$$

where

D_{pj} = particle diameter, cm
L = mean free path of the gas, cm, given by:*

$$L = 1.04 \ \frac{\mu}{P_s} \ \sqrt{1 + 0.00367T} \qquad (15\text{-}3)$$

where

μ, P_s, and T are the same as in equation (15-1) and T has units of °C.

* For Standard Air only, 0° to 410°C; maximum error, 2%.

Reference:

- Ranz, W. E., and J. B. Wong, "Impaction of Dust and Smoke Particles." Ind. Eng. Chem., 44:1371-1381, June 1952.
- Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particulate Sizing Techniques for Control Device Evaluation. Environmental Protection Agency. Southern Research Institute. Washington, D. C. Environmental Protection Tech. Series No. EPA-600/2-76-280. 1976. 94p.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	61	x
02	01	1
03	51	+
04	14 02	f $\sqrt{x}$
05	24 06	RCL 6
06	61	x
07	24 02	RCL 2
08	71	÷
09	01	1
10	73	·
11	00	0
12	04	4
13	61	x
14	23 04	STO 4
15	24 01	RCL 1
16	71	÷
17	31	↑
18	15 22	g 1/x
19	73	·
20	04	4
21	04	4
22	61	x
23	32	CHS
24	15 07	g e^x

DISPLAY		KEY ENTRY
LINE	CODE	
25	73	·
26	08	8
27	02	2
28	61	x
29	02	2
30	73	·
31	04	4
32	06	6
33	51	+
34	61	x
35	01	1
36	51	+
37	24 05	RCL 5
38	61	x
39	24 00	RCL 0
40	61	x
41	24 06	RCL 6
42	71	÷
43	24 02	RCL 2
44	71	÷
45	24 03	RCL 3
46	71	÷
47	14 02	f $\sqrt{x}$
48	24 01	RCL 1
49	61	x

REGISTERS	
R_0	0.0707
R_1	D_{p_j}
R_2	P_s
R_3	$(D_c^3 \cdot X)$
R_4	L
R_5	$(Q \cdot \rho_p \cdot P_A)$
R_6	μ
R_7	T

Using Standard Air as the carrier gas: (μ and L are automatically calculated)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute $\sqrt{\Psi_j}$					
	a. Store variables					
	(in. Hg)		P_s	STO	2	
			D_c	↑		
			3	f	y^x	
			X	x		
				STO	3	
			174.4	↑		
			0.406	↑		
	(°C)		T	STO	7	
				x	+	
				EEX	CHS	
				6	x	
				STO	6	
			Q	↑		
	(in. Hg)		P_A	x		
			ρ_p	x		
				STO	5	
			0.0707	STO	0	
	b. Compute $\sqrt{\Psi_j}$	01				
	(μm)		D_{p_j}	EEX	CHS	
				4		
				STO	1	
	(Do j = 1, N for N different		0.00387	RCL	7	
	particle diameters)			R/S		$\sqrt{\Psi_j}$

Example No. 1: Using Standard Air as the carrier gas:
(μ and L are automatically calculated)

P_s = 29.00 in. Hg.
D_c = 0.0353 cm
3
X = 264 holes
174.4
0.406
T = 20°C
10^{-6}
Q= 236 cc/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cc
0.0707

D_{p_1} = 1 μm
x 10^{-4}
0.00367
RCL 7

→ $\sqrt{\Psi_1}$ = 0.358, dimensionless

D_{p_2} = 5 μm
x 10^{-4}
0.00367
RCL 7

→ $\sqrt{\Psi_2}$ = 1.69, dimensionless

Using carrier gases other than Standard Air: (μ and L are entered manually)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute $\sqrt{\Psi_j}$					
	a. Store variables					
	(in. Hg)		P_s	STO	2	
			D_c	↑		
			3	f	y^x	
			X	×		
				STO	3	
			μ	STO	6	
			L	STO	4	
			Q	↑		
	(in. Hg)		P_A	×		
			ρ_p	×		
				STO	5	
			0.0707	STO	0	
	b. Compute $\sqrt{\Psi_j}$	15				
	μm		D_{pj}	EEX	CHS	
				4		
				STO	1	
				GTO		
	(Do j = 1, N for N different			1	5	
	particle diameters)			RCL	4	
				R/S		$\sqrt{\Psi_j}$

Example No. 2: Using carrier gases other than Standard Air:
(μ and L are entered manually)

P_g = 29.0 in. Hg
D_c = 0.0353 cm
3
X = 264 holes
$\mu = 9.15 \times 10^{-5}$ gm/sec-cm
$L = 3.40 \times 10^{-6}$ cm
Q = 236 cm^3/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cm^3
0.0707

D_{p_1} = 1 μm
x 10^{-4}

→ $\sqrt{\Psi_1}$ = 0.487, dimensionless

D_{p_2} = 4 μm
x 10^{-4}

→ $\sqrt{\Psi_2}$ = 1.89, dimensionless

$\sqrt{\Psi}$ CALCULATION - RECTANGULAR SLOTS

The square root of the Stokes number, $\sqrt{\Psi}$, for an impactor stage is a function of geometry and particle size. For a rectangular slot geometry, this number is given by:

$$\sqrt{\Psi_j} = D_{pj} \sqrt{\frac{0.0556 \ (Q \ \rho_p \ P_A) \ C_j}{\mu P_s \ (w^2 \ell)}} \qquad (16\text{-}1)$$

where

$\sqrt{\Psi_j}$ = square root of the Stokes number for this stage for a particle with diameter D_{pj}, dimensionless

D_{pj} = particle diameter (note: spherical particles are assumed), cm

P_s = local absolute pressure downstream of the stage jet, inches Hg

Q = impactor flow rate, cm^3/sec

ρ_p = particle density, gm/cm^3

P_A = absolute pressure at impactor inlet, inches Hg

w = width of the slot, cm

ℓ = total slot length, cm

0.0556 = 1/18, a constant

μ = gas viscosity, gm/cm-sec, given by:*

$$\mu = (174.4 + 0.406 \ T) \times 10^{-6}$$

where

T = gas temperature, °C

C_j = slip correction factor for this particle diameter as given by:

$$C_j = 1 + \frac{2L}{D_{pj}} \left[1.23 + 0.41 \ \text{EXP} \left(-.44 \ \frac{D_{pj}}{L} \right) \right] \qquad (16\text{-}2)$$

where

D_{pj} = particle diameter, cm

L = mean free path of the gas, cm, given by:*

$$L = 1.04 \ \frac{\mu}{P_s} \ \sqrt{1 + 0.00367 \ T} \qquad (16\text{-}3)$$

where

μ, P_s, and T are the same as in equation (16-1), and T has units of °C

* For Standard Air only, 0° to 410°C; maximum error, 2%.

Reference:
- Ranz, W. E. and J. B. Wong. "Impaction of Dust and Smoke Particles." Ind. Eng. Chem., 44:1371-1381, June 1952.
- Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particulate Sizing Techniques for Control Device Evaluation. Environmental Protection Agency. Southern Research Institute. Washington, D. C. Environmental Protection Tech. Series No. EPA-600/2-76-280. 1976. 94 p.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
1	61	x
2	01	1
3	51	÷
4	14 02	f $\sqrt{x}$
5	24 06	RCL 6
6	61	x
7	24 02	RCL 2
8	71	÷
9	01	1
10	73	·
11	00	0
12	04	4
13	61	x
14	23 04	STO 4
15	24 01	RCL 1
16	71	÷
17	31	↑
18	15 22	g 1/x
19	73	·
20	04	4
21	04	4
22	61	x
23	32	CHS
24	15 07	g e^x

DISPLAY		KEY ENTRY
LINE	CODE	
25	73	·
26	08	8
27	02	2
28	61	x
29	02	2
30	73	·
31	04	4
32	06	6
33	51	+
34	61	x
35	01	1
36	51	+
37	24 05	RCL 5
38	61	x
39	24 00	RCL 0
40	61	x
41	24 06	RCL 6
42	71	÷
43	24 02	RCL 2
44	71	÷
45	24 03	RCL 3
46	71	÷
47	14 02	f $\sqrt{x}$
48	24 01	RCL 1
49	61	x

REGISTERS	
R_0	0.0556
R_1	D_{p_j}
R_2	P_s
R_3	$(w^2 \ell)$
R_4	L
R_5	$(Q \cdot P_\rho \cdot P_A)$
R_6	μ
R_7	τ

Using carrier gases other than Standard Air: (μ and L are entered manually)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute $\sqrt{\Psi_j}$					
	a. Store variables					
	(in. Hg)		P_s	STO	2	
			w	↑	x	
			ℓ	x		
				STO	3	
			174.4	↑		
			0.406	↑		
	(°C)		T	STO	7	
				x	+	
				EEX	CHS	
				6	x	μ
				STO	6	
			Q	↑		
	(in. Hg)		P_A	x		
			ρ_p	x		
				STO	5	
			0.0556	STO	0	
	b. Compute $\sqrt{\Psi_j}$	01				
	(μm)		D_{p_j}	EEX	CHS	
				4		
				STO	1	
	(Do j = 1 → N for N different		0.00367	RCL	7	
	particle diameters)			R/S		$\sqrt{\Psi_j}$

Example No. 1: Using Standard Air as the carrier gas:
(μ and L are automatically calculated)

P_s = 29.0 in. Hg
w = 0.036 cm
ℓ = 3.912 cm
174.4
0.406
T = 20°C
10^{-6}
Q = 236 cm^3/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cm^3
0.0556
D_{p_1} = 1 μm
x 10^{-4}
0.00367
RCL 7

→ $\sqrt{\Psi_1}$ = 0.481, dimensionless

D_{p_2} = 5 μm
x 10^{-4}
0.00367
RCL 7

→ $\sqrt{\Psi_2}$ = 2.26, dimensionless

Using carrier gases other than Standard Air: (μ and L are entered manually)

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute Ψ_j					
	a. Store variables					
			P_s	STO	2	
			w	↑	×	
			ρ	×		
				STO	3	
			μ	STO	6	
			L	STO	4	
			Q	↑		
	(in. Hg)		P_A	×		
			ρ_p	×		
				STO	5	
	b. Compute $\sqrt{\Psi_j}$					
	(μm)		D_{p_j}	EEX	CHS	
				4		
				STO	1	
				GTO		
	(Do j = 1, N for N different			1	5	
	particle diameters)			RCL	4	
		15		R/S		$\sqrt{\Psi_j}$

Example No. 2: Using carrier gases other than Standard Air:
(μ and L are entered manually)

P_S = 29.0 in. Hg
w = 0.036 cm
ℓ = 3.912 cm
μ = 9.15×10^{-5} gm/sec-cm
L = 3.40×10^{-6} cm
Q = 236 cm^3/sec
P_A = 30.00 in. Hg
ρ_p = 1.35 gm/cm^3

D_{p_1} = 1 μm
x 10^{-4}

→ $\sqrt{\Psi_1}$ = 0.654, dimensionless

D_{p_2} = 4 μm
x 10^{-4}

→ $\sqrt{\Psi_2}$ = 2.54, dimensionless

CUMULATIVE CONCENTRATION vs. D_{50}
AND
$\Delta M/\Delta \log D$ vs. GEOMETRIC MEAN DIAMETER

The cumulative concentration for stage index number i ($c_{i,cum}$) is defined to be the sum of the concentrations for all stages having a D_{50} smaller than the D_{50} for stage index number i. Thus for an impactor having a cyclone, six stages, and a backup filter (where the stage index numbers are assigned such that the D_{50}'s are decreasing for increasing index numbers, i.e., $D_{i+1} < D_i$) the cumulative concentration for stage index number five ($c_{5,cum}$) is the sum of the concentrations for stage index numbers eight, seven, and six (i.e., $c_8 + c_7 + c_6$). This is expressed by the following:

$$c_{j,cum} = \sum_{i=j-1}^{N} c_i \qquad (17\text{-}1)$$

where

$c_{j,cum}$ = cumulative concentration of all particles having diameter smaller than the D_{50} for stage index number j

c_i = mass concentration (mass per unit volume) for stage index number i

N = total number of stage index numbers where stage number N has the smallest D_{50}

A cumulative concentration curve plots cumulative concentration against the D_{50} for the index number (i.e., $c_{j,cum}$ vs. D_j).

The differential of a cumulative mass curve is given by:

$$(\Delta M/\Delta \log D)_i = \frac{c_i}{\log(D_{i-1}) - \log(D_i)} \qquad (17\text{-}2)$$

where

$(\Delta M/\Delta \log D)_i$ = differential of the cumulative mass curve for the size band (D_{i-1}, D_i)

D_i = D_{50} for stage index number i

D_{i-1} = D_{50} for stage index number i-1 ($D_{i-1} > D_i$)

c_i = mass concentration for stage index number i, given by:

$$c_i = m_i/V_T \qquad (17\text{-}3)$$

where

m_i = stage weight for stage index number i

V_T = total volume of gas sampled through the impactor, as given in APol-13

Choice of units for V_T (i.e., stack conditions, wet; engineering standard conditions, dry; etc.) and m_i (i.e., mg, grams, grains, etc.) determine the units for $(\Delta M/\Delta \log D)_i$ and $c_{i,cum}$ (i.e., mg/ACM, mg/DSCM, etc.).

The geometric mean diameter, GMD_i, is given by:

$$GMD_i = \sqrt{D_i \times D_{i-1}} \qquad (17\text{-}4)$$

A $\Delta M/\Delta \log D$ curve plots $(\Delta M/\Delta \log D)_i$ against GMD_i.

NOTE:
- Choice of units for V_T and m_i determine the units of $(\Delta M/\Delta \log D)_i$ and $c_{i,cum}$
- By convention, a minimum diameter for the filter catch is usually assigned a value of one half that of the D_{50} for the last stage of the impactor.
- For i = 1, D_{i-1} is taken to be the maximum particle diameter as determined by microscopic examination of the particles collected on the first stage (or cyclone when used).
- 1.00 lb = 7,000 grains
- 1.00 gm = 2.505×10^{-3} lbs
- 1.00 m^3 = 10^3 liters = 35.31 ft^3
- 1.00 mg/m^3 = 4.371×10^{-2} gr/ft^3 = 6.242×10^{-8} lb/ft^3

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	23 06	STO 6
02	22	R ↓
03	23 05	STO 5
04	24 02	RCL 2
05	74	R/S
06	24 03	RCL 3
07	74	R/S
08	24 07	RCL 7
09	74	R/S
10	24 03	RCL 3
11	24 05	RCL 5
12	61	x
13	14 02	f $\sqrt{x}$
14	74	R/S
15	24 04	RCL 4
16	24 02	RCL 1
17	71	÷
18	23 51 07	STO + 7
19	24 05	RCL 5
20	14 08	f log
21	24 03	RCL 3
22	14 08	f log
23	41	–
24	71	÷

DISPLAY		KEY ENTRY
LINE	CODE	
25	01	1
26	23 41 02	STO – 2
27	24 05	RCL 5
28	23 03	STO 3
29	34	CLX
30	24 06	RCL 6
31	23 04	STO 4
32	22	R ↓
33	22	R ↓
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	
R_1	V_T
R_2	i
R_3	D_i
R_4	m_i
R_5	D_{i-1}
R_6	m_{i-1}
R_7	cum

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Compute values for Stage					
	Index No. i					
	a. Store variables					
	(ft^3)		V_T	↑		
			.0283	×		
				STO	1	
			N	STO	2	
	(μm)		D_N	STO	3	
	(mg)		m_N	STO	4	
			0.00	STO	7	
	b. Compute for Stage Index No. i	01				
	(μm)		D_{i-1}	↑		
	(mg)		m_{i-1}	R/S		i
	(μm)	06		R/S		D_i
	(mg/m^3)	08		R/S		$c_{i,cum}$
	(μm)	10		R/S		GMD_i
	(mg/m^3)	15		R/S		$(\Delta M/\Delta \log D)_i$
	Do i = N → 1, decreasing					
4	Convert $mg/m^3 \rightarrow gr/ft^3$		mg/m^3	↑		
			0.4371	×		gr/ft^3
5	Convert $mg/m^3 \rightarrow lb/ft^3$		mg/m^3	↑		
			6.242×10^{-8}	×		lb/ft^3
6	Convert $ft^3 \rightarrow m^3$		ft^3	↑		
			0.0283	×		m^3

EXAMPLE:

For a six stage impactor, with cyclone, D_{50}'s and stage weights are as follow:

STAGE ID	INDEX No.	D_{50} (μm)	STAGE WEIGHT (mg)
	0	55*	
Cyclone	1	9.00	1.13
SO	2	6.60	0.63
S1	3	3.73	0.21
S2	4	2.20	0.20
S3	5	1.52	0.49
S4	6	0.79	3.38
S5	7	0.55	2.04
Filter	8	0.28**	0.45

* maximum particle diameter $V_T = 0.40$ ft^3, dry, standard conditions

** by convention; $D_{50} = ½ D_7$

Store variables:

V_T = 0.40 DSCF (from equation (13-2))
0.0283
N = 8
D_8 = 0.28 μm
m_8 = 0.45 mg
0.000

For Stage Index No. 8 (i.e., Filter):

D_7 = 0.55 μm
m_7 = 2.04 mg

→ i = 8
D_8 = 0.28 μm
$c_{8,cum}$ = 0.00 mg/DSCM
GMD_8 = 0.39 μm
$(\Delta M/\Delta \log D)_8 = 1.36 \times 10^2$ mg/DSCM

For Stage Index No. 7:

$D_6 = 0.79\ \mu m$
$m_6 = 3.38$ mg

→ $i = 7$
$D_7 = 0.55\ \mu m$
$c_{7,\,cum} = 3.98 \times 10^1$ mg/DSCM
$GMD_7 = 0.66\ \mu m$
$(\Delta M/\Delta \log D)_7 = 1.15 \times 10^3$ mg/DSCM

For Stage Index No. 1:

$D_O = 55\ \mu m$
$m_O = 55$***

→ $i = 1$
$D_1 = 9.00\ \mu m$
$c_{1,cum} = 6.54 \times 10^2$ mg/DSCM
$GMD_1 = 22.25\ \mu m$
$(\Delta M/\Delta \log D)_1 = 1.27 \times 10^2$ mg/DSCM

For Stage Index No. 0:

$D_O = 0.00$
$m_O = 0.00$

→ $i = 0$
$D_O = 55\ \mu m$
$c_{O,\,cum} = 7.53 \times 10^2$

Unit Conversions:

5.50 mg/DSCM = 2.40 gr/DSCF
(= 3.43×10^{-4} lb/DSCF)
0.40 ft^3 = $1.13 \times 10^{-2}\ m^3$

*** The value used for m_O is arbitrary since this entry is only used to position the stack so that D_O will be correctly stored.

Tabulated Results

Stage ID	Index No.	Size (μm)	Cum. Conc. (mg/DSCM)	GMD (μm)	$\Delta M/\Delta \log D$ (mg/DSCM)
	0	55	7.54×10^2		
Cyclone	1	9.00	6.54×10^2	22.25	1.27×10^2
SO	2	6.60	5.98×10^2	7.71	4.13×10^2
S1	3	3.73	5.80×10^2	4.96	7.49×10^1
S2	4	2.20	5.62×10^2	2.86	7.71×10^1
S3	5	1.52	5.19×10^2	1.83	2.70×10^2
S4	6	0.79	2.20×10^2	1.10	1.05×10^3
S5	7	0.55	3.98×10^1	0.66	1.15×10^3
Filter	8	0.28*	—	0.39*	1.36×10^2*

* values are somewhat arbitrary and may not be meaningful.

MEAN, STD. DEVIATION, 90/95% CONFIDENCE INTERVALS, MEAN ± CI

The mean ($\bar{x}$) for a set of N numbers, $\{x_i\}$, is given by:

$$\bar{x} = \frac{(\Sigma\ x_i)}{N} \qquad (18\text{-}1)$$

The standard deviation (σ) for this set of numbers is given by:

$$\sigma = \sqrt{\lambda/(N-1)} \qquad (18\text{-}2)$$

where

$$\lambda = (\Sigma x_i^2) - N(\bar{x})^2$$

The relative standard deviation is given by:

$$RSD = \sigma/\bar{x} \qquad (18\text{-}3)$$

The 90% (or 95%, depending on our choice of c_1, c_2, & c_3) confidence interval (CI) is approximated by:

$$\begin{aligned} CI &= T(\sigma/\sqrt{N}) \\ &= \left[c_1 + c_2\,(N-1)^{c_3}\right]\ (\sigma/\sqrt{N}) \qquad (18\text{-}4) \end{aligned}$$

where

c_1, c_2, and c_3 are constants for $N \geq 3$:

For the 90% CI; $c_1 = 1.645$, $c_2 = 2.605$, $c_3 = -1.186$

For the 95% CI; $c_1 = 1.960$, $c_2 = 5.550$, $c_3 = -1.346$

The lower confidence limit (LCL) is given by:

$$LCL = \bar{x} - CI$$

The upper confidence limit (UCL) is given by:

$$UCL = \bar{x} + CI$$

Note:

- Units are determined by the choice of units for $\{x_i\}$
- For N = 2 or 3, T has the following value:
  90% CI: N = 2, T = 6.314; N = 3, T = 2.920
  95% CI: N = 2, T = 12.71; N = 3, T = 4.303
- For 50% confidence intervals:
  $c_1 = 0.674$ $c_2 = 0.32$, $c_3 = -1.072$

Reference: Dixon, W. J., and F. J. Massey, Jr. Introduction to Statistical Analysis. Second ed. New York, McGraw-Hill, 1957. p. 127, 128, 384.

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	23 51 05	STO + 5
02	15 02	g x^2
03	23 51 06	STO + 6
04	01	1
05	23 51 04	STO + 4
06	24 04	RCL 4
07	13 00	GTO 00
08	24 06	RCL 6
09	24 05	RCL 5
10	24 04	RCL 4
11	71	÷
12	23 07	STO 7
13	74	R/S
14	15 02	g x^2
15	24 04	RCL 4
16	61	x
17	41	–
18	24 04	RCL 4
19	01	1
20	41	–
21	71	÷
22	14 02	f $\sqrt{x}$
23	23 00	STO 0
24	74	R/S
25	24 07	RCL 7
26	71	÷
27	74	R/S
28	24 00	RCL 0
29	24 04	RCL 4
30	14 02	f $\sqrt{x}$
31	71	÷
32	24 04	RCL 4
33	01	1
34	41	–
35	24 03	RCL 3
36	14 03	f y^x
37	24 02	RCL 2
38	61	x
39	24 01	RCL 1
40	51	+
41	61	x
42	23 04	STO 4
43	74	R/S
44	24 07	RCL 7
45	51	+
46	74	R/S
47	24 07	RCL 7
48	24 04	RCL 4
49	41	–

REGISTERS	
R_0	σ
R_1	C_1
R_2	C_2
R_3	C_3
R_4	n, CI
R_5	ΣX_i
R_6	ΣX_i^2
R_7	$\bar{x}$

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Load Constants					
	a. For 90% confidence intervals		1.645	STO	1	
			2.605	STO	2	
			-1.186	STO	3	
	or					
	b. For 95% confidence intervals		1.960	STO	1	
			5.550	STO	2	
			-1.346	STO	3	
4	Compute values					
	a. Initalize Σ registers		0.00	STO	4	
			0.00	STO	5	
			0.00	STO	6	
	b. Enter data points x_i	01	x_i	R/S		i
	(To correct for erroneous x_i, see					
	Step 5.)					
	(Do i = 1, N)					
	c. Compute $\overline{x}$			GTO	08	
		08		R/S		$\overline{x}$
	d. Compute σ	14		R/S		σ
	e. Compute RSD	25		R/S		$\sigma/\overline{x}$
	f. Compute CI	28		R/S		CI
	g. Compute UCL	44		R/S		UCl
	h. Compute LCL	47		R/S		LCl

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS	DISPLAY
5	To determine the effect of omitting				
	a point x_j from the data set:		N	↑	
			1	−	
				STO 4	
			x_j	↑	
				STO −	
				5 ×	
				STO −	
				6	
				GTO 08	
	(Proceed as in 4c above)			R/S	$\bar{x}$
6	For a new data sets, go to Step 4a.				

Example:

Initalize Σ registers:

0.00

Given the following set of 4 numbers:

$$\left.\begin{array}{l} x_1 = 0.395 \\ x_2 = 0.384 \\ x_3 = 0.383 \\ x_4 = 0.385 \end{array}\right\} \rightarrow \begin{array}{r} N = 4 \\ \bar{x} = 3.87 \times 10^{-1} \\ \sigma = 5.56 \times 10^{-3} \\ \sigma/\bar{x} = 1.44 \times 10^{-2} \text{ (i.e., 1.44\%)} \end{array}$$

For 90% CI:

$CI = 6.54 \times 10^{-3}$

$UCI = 3.93 \times 10^{-1}$

$LCI = 3.80 \times 10^{-1}$

For 95% CI:

$CI = 8.97 \times 10^{-3}$

$UCI = 3.96 \times 10^{-1}$

$LCI = 3.78 \times 10^{-1}$

If x_1 (i.e., $x_1 = 0.395$) is eliminated from the set:

N = 4
1
$x_1 = 0.395$

$$\rightarrow \quad \overline{x} = 3.84 \times 10^{-1}$$

$$\sigma = 1.00 \times 10^{-3}$$

$$\sigma/\overline{x} = 2.60 \times 10^{-3} \text{ (i.e., 0.260\%)}$$

$$95\% \text{ CI} = 2.39 \times 10^{-3}$$

RESISTIVITY AND ELECTRIC FIELD STRENGTH

For a point plane resistivity probe, the resistivity, (ρ) of a layer of fly ash collected on the probe is given by:

$$\rho = \frac{V\ A}{I\ L} \tag{19-1}$$

where

V = voltage across the layer of fly ash, volts
I = current through the layer of fly ash, amps
A = area of the layer of fly ash, cm^2
L = thickness of the layer of fly ash, cm

The electric field strength (E) is given by:

$$E = \frac{V}{L} \tag{19-2}$$

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	23 04	STO 4
02	21	x⇌y
03	23 03	STO 3
04	21	x⇌y
05	71	÷
06	24 01	RCL 1
07	61	x
08	24 02	RCL 2
09	71	÷
10	74	R/S
11	24 03	RCL 3
12	24 02	RCL 2
13	71	÷
14	74	R/S
15	13 00	GTO 00
16	13 00	GTO 00
17	13 00	GTO 00
18	13 00	GTO 00
19	13 00	GTO 00
20	13 00	GTO 00
21	13 00	GTO 00
22	13 00	GTO 00
23	13 00	GTO 00
24	13 00	GTO 00
25	13 00	GTO 00
26	13 00	GTO 00
27	13 00	GTO 00
28	13 00	GTO 00
29	13 00	GTO 00
30	13 00	GTO 00
31	13 00	GTO 00
32	13 00	GTO 00
33	13 00	GTO 00
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	A
R_1	L
R_2	V
R_3	I
R_4	
R_5	
R_6	
R_7	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS	DISPLAY
1	PRGM mode; clear program then			f PRGM	
	key in program steps			⋮	
2	RUN mode: Initialize			f PRGM	
3	Compute ρ and E				
	a. Store variables		A	STO 1	
			L	STO 2	
	b. Compute ρ and E	01	V	↑	
			I	R/S	ρ
		11		R/S	E
4	To compute E only		V	↑	
			L	÷	E

Example:

$A = 5.00\ \text{cm}^2$
$L = 0.100\ \text{cm}$

$V = 1{,}000\ \text{volts}$
$I = 0.00100\ \text{amps}$

→ $\rho = 5.00 \times 10^7$ ohm-cm
$E = 1 \times 10^4$ volts/cm

CHANNEL CONCENTRATIONS FOR THE KLD DROPLET MEASURING DEVICE (1-600 μm), DC-1

As described in EPA-650/2-75-018, Environmental Protection Technology Series, "Design, Development, and Field Test of A Droplet Measuring Device," the droplet concentration, n_i for each of the six channels is given by the following:

$$n_i = \frac{N_i}{V \; t \; \ell \; (2D_i + d)} \qquad (i = 1,6) \qquad (20\text{-}1)$$

where

n_i = droplet concentration for the i^{th} channel, droplets/cm^3
N_i = total number of droplets counted in the i^{th} channel
V = flow velocity, cm/sec
t = time interval, sec
ℓ = sensor length, cm
D_i = average droplet diameter for the i^{th} channel, cm
d = sensor wire diameter, 5×10^{-4} cm

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 02	RCL 2
02	71	÷
03	24 01	RCL 1
04	71	÷
05	24 03	RCL 3
06	71	÷
07	21	x⇌y
08	02	2
09	61	x
10	24 04	RCL 4
11	51	+
12	71	÷
13	13 00	GTO 00
14	13 00	GTO 00
15	13 00	GTO 00
16	13 00	GTO 00
17	13 00	GTO 00
18	13 00	GTO 00
19	13 00	GTO 00
20	13 00	GTO 00
21	13 00	GTO 00
22	13 00	GTO 00
23	13 00	GTO 00
24	13 00	GTO 00
25	13 00	GTO 00
26	13 00	GTO 00
27	13 00	GTO 00
28	13 00	GTO 00
29	13 00	GTO 00
30	13 00	GTO 00
31	13 00	GTO 00
32	13 00	GTO 00
33	13 00	GTO 00
34	13 00	GTO 00
35	13 00	GTO 00
36	13 00	GTO 00
37	13 00	GTO 00
38	13 00	GTO 00
39	13 00	GTO 00
40	13 00	GTO 00
41	13 00	GTO 00
42	13 00	GTO 00
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	
R_1	t
R_2	V
R_3	ℓ
R_4	d
R_5	D_i
R_6	N_i
R_7	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS	DISPLAY
1	PRGM mode; clear program then			f PRGM	
	key in program steps			⋮	
2	RUN mode: Initialize			f PRGM	
3	Compute n_i				
	a. Store variables (sec)		t	STO 1	
			V	STO 2	
			ℓ	STO 3	
			d	STO 4	
	b. Compute n_i	01	D_i	↑	
	Do $i = 1 \rightarrow 6$		N_i	R/S	n_i

Example:

Store variables:

$t = 130$ sec

$V = 311$ cm/sec

$\ell = 0.10$ cm

$d = 5 \times 10^{-4}$ cm

Channel No. 1:

$D_1 = 1.40 \times 10^{-4}$ cm

$N_1 = 505$

$\rightarrow n_1 = 160$ droplets/cm^3

Channel No. 2:

$D_2 = 2.15 \times 10^{-4}$ cm

$N_2 = 290$

$\rightarrow n_2 = 77$ droplets/cm^3

AEROTHERM HIGH VOLUME STACK SAMPLER

STACK VELOCITY, NOZZLE DIAMETER, ISOKINETIC ΔH

As detailed in the operation manual for the Aerotherm High Volume Stack Sampler, the stack velocity (as given by the Type S pitot) is given by:

$$V_s = K' \ C_p \ \sqrt{\frac{\Delta p \ T_s}{M_s}} \qquad (21\text{-}1)$$

where

V_s = point velocity of stack gas, m/sec

C_p = pitot tube coefficient, dimensionless

Δp = velocity head of the stack gas for the pitot at this point, (pitot Δp), cm H_2O

T_s = absolute stack gas temperature at this point, °K

M_s = molecular weight of stack gas (wet basis), gm/gm-mole

K' = an intermediate value, given by:

$$K' = 34.96 \ \frac{\text{m}}{\text{sec}} \left(\frac{\text{gm}}{\text{gm-mole-°K}} \right)^{1/2} (P_s)^{-1/2} \qquad (21\text{-}2)$$

where

P_s = pressure of the stack gas, absolute, cm Hg

For P_s = 75 cm Hg (29.53 inches Hg), K' has the value 4.037

When the velocity is known and a desired flow rate chosen, the appropriate nozzle can be selected from the following:

$$D_N = 0.461 \sqrt{\frac{T_s \ Q_m}{V_s \ B_d \ T_m \ (P_s/P_m)}} \qquad (21\text{-}3)$$

where

D_N = correct nozzle diameter for obtaining the desired isokinetic flow rate, cm

$$0.461 = \left[\left(\frac{4}{\pi}\right) \ \frac{10^4}{60 \ \times \ 10^3} \right]^{1/2} \ \text{cm} \left(\frac{\text{m/sec}}{\text{l/min}} \right)^{1/2}$$

Q_m = the desired flow rate, meter conditions, l/min
T_m = absolute meter temperature, °K
P_s/P_m = ratio of absolute stack pressure and absolute pressure at the meter
B_d = dry gas fraction given by:

$$B_d = (1-B_{wo})$$

where

B_{wo} = proportion by volume of water vapor in the stack gas (Method 4, equation (4-3))

T_s and V_s are as given in equation (21-1) above.

The next smaller available nozzle size should be used in the particular sampling application.

The correct pressure drop, ΔH_i, for isokinetic sampling is given by:

$$\Delta H_i = \frac{T_m \ \Delta p_i}{T_s}\left[\frac{(D_N')^2 \ C_p \ B_d}{JD_o^2}\right]^2\left[\frac{(P_s/P_m) \ M_d}{M_s}\right] \qquad (21\text{-}4)$$

where

ΔH_i = required velocity head across the orifice, cm H_2O, to obtain isokinetic sampling with the given nozzle diameter, D_N', at traverse point i
Δp_i = velocity head of the stack gas for the pitot at traverse point i, cm H_2O
D_N' = diameter of the nozzle selected, cm
JD_o^2 = orifice constant given by:

$$JD_o^2 = (J) \ (D_o)^2$$

where

J = orifice constant, dimensionless
D_o = diameter of sharp edged orifice, cm
M_d = dry molecular weight of the flue gas (Method 3, equation (3-2)), gm/gm-mole

T_m, (P_s/P_m), B_d, M_s, T_s, C_p, and V_s are as defined for equation (21-1) and (21-3) above.

PROCEDURE

Step 1 Select all traverse points on the duct to be sampled. Let N be the total number of points selected.

Step 2 Obtain pitot data for each of these N points $\left\{(\Delta p_i, T_i); i = 1,N)\right\}$

Step 3 Using the extremes from this set, select a nozzle, D_N', using equation (21-3). In selecting the desired meter flow rate, Q_m, be sure that adequate pump capacity will be available for maintaining isokinetic sampling when the pressure drop across the filter increases as the filter loads up.

Step 4 Using D_N' and the extremes of the data set (Δp_i, T_i); i = 1,N , select one orifice (from among those available) for which good ΔH_i values (greater than 1.27 cm) can be obtained at all traverse points.

Step 5 Having selected D_N' and one orifice (jD_o^2), obtain the run data, (ΔH_i, Δp_i), for each traverse point by using equation (21-4).

Note:
- 1.00 inch = 2.540 cm
- 1.00 foot = 0.3048 m

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	24 00	RCL 0
02	61	x
03	14 02	f $\sqrt{x}$
04	24 01	RCL 1
05	61	x
06	61	x
07	74	R/S
08	24 00	RCL 0
09	61	x
10	21	x⇌y
11	71	÷
12	24 05	RCL 5
13	71	÷
14	24 04	RCL 4
15	71	÷
16	14 02	f $\sqrt{x}$
17	73	·
18	04	4
19	06	6
20	01	1
21	61	x
22	74	R/S
23	23 00	STO 0
24	21	x⇌y
25	24 04	RCL 4
26	61	x
27	24 00	RCL 0
28	71	÷
29	24 06	RCL 6
30	61	x
31	24 03	RCL 3
32	15 02	g x^2
33	24 01	RCL 1
34	61	x
35	24 05	RCL 5
36	61	x
37	24 02	RCL 2
38	71	÷
39	15 02	g x^2
40	61	x
41	74	R/S
42	13 23	GTO 23
43	13 00	GTO 00
44	13 00	GTO 00
45	13 00	GTO 00
46	13 00	GTO 00
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	T_s
R_1	$C_p/\sqrt{M_s}$
R_2	$J D_o^2$
R_3	D_N'
R_4	$T_m(P_s/P_m)$
R_5	B_d
R_6	M_d
R_7	V_s

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS	DISPLAY
1	PRGM mode; clear program then			f PRGM	
	key in program steps			⋮	
2	RUN mode: Initialize			f PRGM	
3	Compute stack velocity				
	a. Store variables				
	(°C)		T_s	↑	
			273.2	+	
				STO 0	
			C_p	↑	
			M_s	f √x	
				÷	
				STO 1	
	b. Compute V_s	01	34.96	↑	
			P_s	f √x	
				÷	K
	(cm H_2O)		Δp	R/S	V_s
				STO 7	
4	Select nozzle size				
	a. Store variables				
	(°C)		T_m	↑	
			273.2	+	
			P_s	×	
			P_m	÷	
				STO 4	
			B_d	STO 5	
			(T_s)	STO 0	
	b. Compute D_N	08		RCL 7	V_s
			Q_m	R/S	D_N
	c. Select the next smaller available				
	nozzle size				
	($D_N' < D_N$)		D_N'	STO 3	

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
5	Compute isokinetic run data			☐	☐	
	a. Store variables		$(C_p/\sqrt{M_s})$	STO	1	
			JD_o^2	STO	2	
			(D_N')	STO	3	
			*	STO	4	
			(B_d)	STO	5	
			M_d	STO	6	
	b. Compute isokinetic run data			☐	☐	
	$(\Delta H_i,\ \Delta p_i)$		Δp_i	↑	☐	
	(°C)		T_s	↑	☐	
	(cm H_2O)		273.2	+	R/S	ΔH_i

* $(T_m(P_s/P_m))$

Example:

Given the following set of traverse data, select a nozzle diameter and orifice, then calculate $(\Delta H_i,\ \Delta p_i)$ run data:

		Traverse Point					
Port	Data	1	2	3	4	5	6
A	$\Delta p_i(cmH_2O)$	9.50	10.15	9.75	9.60	9.45	9.25
	T_{s_i}(°C)	147	149	147	146	146	145
B	$\Delta p_i(cmH_2O)$	9.65	9.85	9.75	9.70	9.45	9.30
	T_{s_i}(°C)	146	148	147	147	147	145

Available nozzles: 1/4 inch (0.6350 cm); 3/8 inch (0.9525 cm);
1/2 inch (1.270 cm); 9/16 inch (1.429 cm);
5/8 inch (1.588 cm)

Available orifices:

$J_1 = 0.690$
$D_1 = 0.480$ cm
$(JD_o^2)_1 = 0.159\ cm^2$

$J_2 = 0.770$
$D_2 = 0.716$ cm
$(JD_o^2)_2 = 0.395\ cm^2$

$J_3 = 1.00$
$D_3 = 0.905$
$(JD_o^2)_3 = 0.819\ cm^2$

Selecting D_N' Based on Maximum V_s:

Max T_{s_k} = 149°C
273.2
C_p = 0.85
M_s = 26.80 gm/gm-mole
34.96
P_s = 75.95 cm Hg
Max Δp_k = 10.15 cm H_2O

→ Max V_s = 4.31×10^1 m/sec
(STO 7)

T_m = 37.8°C
273.2
P_s = 75.95 cm Hg
P_m = 76.00 cm Hg
B_d = 0.80
RCL 7
Q_m = 113 ℓ/min

→ D_N = 9.73×10^{-1} cm H_2O

Thus we would select D_N' = 0.9525 cm (STO 3)

Selecting $J\,D_o^2$ For Best ΔH, Given D_N':

For Maximum ΔH:

$(J\,D_o^2)_1$ = 0.159 cm² (first guess)
M_d = 29.00 gm/gm-mole

Max Δp_k = 10.15 cm H_2O
T_{s_k} = 149°C
273.2

→ Max ΔH_k = 1.22×10^2 cm H_2O

ΔH is too high thus we will try a different orifice, $(J\,D_o^2)_3$

$(J\,D_o^2)_3$ = 0.819 cm²

Max Δp_k = 10.15 cm H_2O
T_{s_k} = 149°C
273.2

→ Max ΔH_k = 4.59 cm H_2O

For minimum ΔH:

$(J\,D_O^2)_3$ = (already stored in No. 2)

min Δp_j = 9.25 cm H_2O

T_{s_j} = 145°C

273.2

$\rightarrow$ min $\Delta H_j = 4.22$ cm H_2O

Thus we would select $(J\,D_O^2)_3$ as our orifice.

Computing Run Data:

For Port A:

Δp_1 = 9.50 cm H_2O

T_{s_1} = 147°C

273.2

$\rightarrow$ $\Delta H_1 = 4.31$ cm H_2O

Δp_2 = 10.15 cm H_2O

T_{s_2} = 149°C

273.2

$\rightarrow$ $\Delta H_2 = 4.59$ cm H_2O

Δp_3 = 9.75 cm H_2O

T_{s_3} = 147°C

273.2

$\rightarrow$ $\Delta H_3 = 4.43$ cm H_2O

Tabulated ΔH_i (cm H_2O)

	1	2	3	4	5	6
Port A	4.31	4.59	4.43	4.37	4.30	4.22
Port B	4.39	4.46	4.43	4.41	4.29	4.24

FLAME PHOTOMETRIC DETECTOR CALIBRATION BY PERMEATION TUBE TECHNIQUE

The calibration of a flame photometric detector (FPD) by use of a permeation tube has been described by R. K. Stephens.[1] For a continuous flow of gas over the permeation tube, the concentration, in parts per million (ppm), of permeand contained in the carrier gas flowing over the tube is given by:

$$C = \frac{Pr}{M} \times \frac{G}{L} \qquad (22\text{-}1)$$

where

C = concentration of permeand transferred to a gas flowing over the permeation tube, ppm

Pr = permeation rate (from gravimetric determination of weight loss due to permeation), μg/min

M = molecular weight of the gas inside the permeation tube, g/g-mole

G = volume per g-mole, as given by the ideal gas law, for this gas at a stated temperature and pressure, liters/g-mole (G = 24.1 l/g-mole at 20.3°C and one atm)

L = flow rate of the clean dilution air, liters/min

By adjusting the dilution air flow rate (L) one can obtain the desired permeand concentration.

For sulfur dioxide, hydrogen sulfide, methyl mercaptan, and carbon disulfide the instrument response (of the FPD) and the concentration (of the gas) are linear in the natural log, thus:

$$\ln C = m \times \ln(\text{Instrument Response}) + B \qquad (22\text{-}2)$$

where

ln C = natural logarithm of the concentration of the gas, for C in ppm

m = slope of the line as determined by calibration data

B = background value (i.e., y-intercept) as determined by calibration data

Instrument Response = magnitude of the response of the FPD to a certain concentration as given by the product of the attenuation and scale fraction (SF)

Thus the concentration associated with an instrument response (IR) is given by:

$$C = \exp\left\{ m \times \ln(\text{Instrument Response}) + B \right\} \qquad (22\text{-}3)$$

where

C, m, Instrument Response, and B are as defined above.

For a given instrument the value for "m" and "B" are determined by calibration with a permeation tube. Equation (22-1) is used to calculate the concentration C_i that gives rise to an instrument response IR_i. By using several concentrations and ploting ln C_i vs ln IR_i the value of "m" and "B" can be determined from a least squares curve fit. Once "m" and "B" have been determined from the calibration data, equation (22-3) can be used to calculate unknown concentrations of this gaseous compounds.

Note: R = 0.08205 liter-atm/mole-K°

Reference:

1. Stephens, R. K., A. E. O'Keefe and G. C. Ortman, "Absolute Calibration of a Flame Photometric Detector to Volatile Sulfur Compounds at Sub-Part-Per-Million Levels". Environmental Science & Technology, 3, No. 7, pp. 652-55 (1969).

DISPLAY		KEY ENTRY
LINE	CODE	
00		
01	61	x
02	21	x⇌y
03	24 00	RCL 0
04	21	x⇌y
05	71	÷
06	14 07	f ln
07	21	x⇌y
08	14 07	f ln
09	25	Σ +
10	13 00	GTO 00
11	24 05	RCL 5
12	24 07	RCL 7
13	24 04	RCL 4
14	61	x
15	24 03	RCL 3
16	71	÷
17	41	–
18	24 06	RCL 6
19	24 07	RCL 7
20	15 02	g x^2
21	24 03	RCL 3
22	71	÷
23	41	–
24	71	÷
25	23 01	STO 1
26	24 07	RCL 7
27	24 03	RCL 3
28	71	÷
29	61	x
30	24 04	RCL 4
31	24 03	RCL 3
32	71	÷
33	21	x⇌y
34	41	–
35	23 02	STO 2
36	24 01	RCL 1
37	74	R/S
38	61	x
39	14 07	f ln
40	24 01	RCL 1
41	61	x
42	24 02	RCL 2
43	51	+
44	15 07	g e^x
45	74	R/S
46	13 38	GTO 38
47	13 00	GTO 00
48	13 00	GTO 00
49	13 00	GTO 00

REGISTERS	
R_0	$(\frac{Pr\ G}{M})$
R_1	m
R_2	B
R_3	n
R_4	Σy
R_5	Σxy
R_6	Σx^2
R_7	Σx

STEP	INSTRUCTIONS	LINE NO.	DATA	KEYS		DISPLAY
1	PRGM mode; clear program then			f	PRGM	
	key in program steps			⋮		
2	RUN mode: Initialize			f	PRGM	
3	Determine calibration constants					
	m & B					
	a. Initialize Registers			f	REG	
	b. Store permeation tube constants		Pr	↑		
			G	×		
			M	÷		
				STO	0	
	c. Enter calibration data	01	L	↑		
	(when IR is known directly;		$Attn_i$	↑		
	enter 1.00 for Attn and enter					
	the value for IR_i in place of					
	SF_i)		SF_i	R/S		
	Do i = 1, N for N calibtation pts					
	d. Calculate m and B			GTO	11	
		11		R/S		m
				x⇌y		B
4	Calculate unknown concentrations	38	(m)	STO	2	
			(B)	STO	3	
	(When IR_j is known directly; enter		$Attn_j$	↑		
	1.00 for $Attn_j$ and enter the value					
	for IR_j in place of SF_j)		SF_j	R/S		C_j
	Do j = 1, K for K unknowns					

Example:

Calibration Data

SO_2 Permeation Tube No. 2 Instrument ID No. A96257

Pr = 2 μg/min
G = 24.1 l/min (20.3°C and 1.00 atm pressure)
M = 64 g/g-mole

(L , Attn , SF)
(0.81 ℓ/min, x 10^{-5}, 0.75)
(6.85 ℓ/min, x 10^{-7}, 1.00)
(10 ℓ/min, x 10^{-7}, 0.54)

→ m = 0.504
B = 5.88

Unknown Concentrations

(Attn , SF)
(x 10^{-8}, 0.65) → C = 0.0267 ppm
(x 10^{-6}, 0.90) → C = 0.321 ppm

Calibration Data
(when IR is known directly)

Pr = 2 μg/min
G = 24.1 l/min (20.3°C and 1.00 atm pressure)
M = 64 g/g-mole

(L , 100, IR)
(0.84 ℓ/min, 100, 5.6 x 10^{-6})
(3.80 ℓ/min, 100, 3.2 x 10^{-7})
(23.0 ℓ/min, 100, 1.0 x 10^{-8})

→ m = 0.523
B = 6.21

SECTION V

APPENDICES

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APPENDIX A

BRIEF OPERATING INSTRUCTIONS

The following gives a brief review of operating instructions for the HP-25. For more extensive instruction the reader is referred to the HP-25 owner's handbook.

The $\boxed{f}$ $\boxed{\text{FIX}}$, $\boxed{f}$ $\boxed{\text{SCI}}$, and $\boxed{f}$ $\boxed{\text{ENG}}$ keys are used to set the display mode to fixed decimal notation, scientific notation, or engineering notation, respectively. The HP-25 uses RPN logic, rather than algebraic logic, thus the negative number "–24" would be entered as follows: $\boxed{2}$, $\boxed{4}$, $\boxed{\text{CHS}}$, $\boxed{\uparrow}$. The number "2.4×10^{-6}" would be entered as $\boxed{2}$, $\boxed{\cdot}$, $\boxed{4}$, $\boxed{\text{EEX}}$, $\boxed{\text{CHS}}$, $\boxed{6}$, $\boxed{\uparrow}$. To clear a number from the X register (display register) without shifting the stack, use $\boxed{\text{CLX}}$. Numbers are stored and manipulated in the machine "registers". Each number, no matter how few digits or how many, occupies one entire register. The displayed **X-register**, which is the only visible register, is one of four registers inside the calculator that are positioned to form the automatic memory stack. We label these registers X, Y, Z, and T. They are "stacked" one on top of the other with the X-register on the bottom as illustrated below.

Name	Register
T	4
Z	5
Y	14
X	3

A two number function, such as $\boxed{+}$, $\boxed{-}$, $\boxed{\times}$, and $\boxed{\div}$, would perform the specified operation on the contents of the Y and X registers, thus both numbers must be in the calculator before the function key is pressed. If the stack were loaded as shown above and the $\boxed{-}$ key were pressed, the contents of the X-register would be subtracted from that of the Y-register.

$$\begin{array}{r} 14 \\ -\,3 \\ \hline 11 \end{array}$$

Our new stack would look like this:

Name	Register
T	4
Z	4
Y	5
X	11

Notice that the 14 and 3 have been replaced by the 11 and the contents of the Z and T dropped down. The T maintains its old number even though it was dropped down to the Z-register. Thus a calculation such as $4 + 5\,(2 \times 7 - 3)$ could be performed from left to right by: $\boxed{4}$, $\boxed{\uparrow}$, $\boxed{5}$, $\boxed{\uparrow}$, $\boxed{2}$, $\boxed{\uparrow}$, $\boxed{7}$, $\boxed{\times}$, $\boxed{3}$, $\boxed{-}$ (at this point the stack is as shown above), $\boxed{\times}$, $\boxed{+}$. The answer 59.00 is displayed (X-register).

The above paragraph illustrates manipulations of the 4-register stack. General practice, however, is to start with the inner-most parentheses first and work outward, (the same way one would approach the problem if working it by hand – solving for intermediate results first). Thus the above problem would normally be approached as follows: $\boxed{2}$, $\boxed{\uparrow}$, $\boxed{7}$, $\boxed{x}$, $\boxed{3}$, $\boxed{-}$, $\boxed{5}$, $\boxed{x}$, $\boxed{4}$, $\boxed{+}$, which requires only 10 key strokes rather than 12.

A program is simply a sequence of keystrokes stored in program memory and executed automatically on the contents of the stack (and/or the eight storage registers) when the operator presses (in RUN mode) the $\boxed{\text{R/S}}$ button. The bulk of the programmed steps are the same keys that one would press manually in RUN mode in order to solve the equation. The program memory of the HP-25 consists of forty-nine labeled and addressable subdivisions referred to as program lines, each of which causes the execution of one or more key strokes. Program execution is controlled by means of an internal program pointer. Pressing the $\boxed{\text{R/S}}$ button (in RUN mode) causes execution of the program to begin from that program line number (inclusive) where the pointer is positioned and to continue sequentially to higher line numbers until either a branch command or a halt command is encountered. A halt occurs when either a programmed $\boxed{\text{R/S}}$ command (74) is encountered or an invalid operation is attempted (resulting in an $\boxed{\text{ERROR}}$ display; see page 109 of the Owner's Handbook). Program execution is also halted when line number $\boxed{00\qquad\qquad}$ is encountered. A branch command would cause the program pointer to shift to a specific line number and continue execution sequentially from that point in memory.

To enter a program set the PRGM-RUN switch to PRGM. Clear the program memory of previous programs (and position the program pointer to the top of memory – LINE NO. 00) by pressing $\boxed{\text{f}}$ $\boxed{\text{PRGM}}$, then key in the desired sequence of keystrokes. Switch back to RUN mode. Position the program pointer back to the top of memory by pressing $\boxed{\text{f}}\boxed{\text{PRGM}}$(while in RUN mode).

Once the keystroke procedure for solving a particular problem has been written and recorded in the program memory, one need no longer devote attention to the individual keystrokes that make up the procedure. To execute the program simply position the program pointer at the proper location in memory, enter the specific values for all DATA variables as directed by the program INSTRUCTIONS and press $\boxed{\text{R/S}}$. The sequence of keystrokes is executed automatically and the result is displayed in the X-register when the program pointer comes to a command that halts execution.

The contents of the program memory may be reviewed at any time by using the $\boxed{\text{SST}}$ key (single step) and the $\boxed{\text{BST}}$ key (back step). In PRGM mode these keys cause the location (line number) and key strokes codes (row and column) to be displayed. For example, if the key stroke $\boxed{\text{R/S}}$ was stored on line five of program memory, the display would show $\boxed{05\qquad 74}$ because we are on line 05 (two digit address required) and this key is located on the 7th row and 4th column. If the merged key stroke $\boxed{\text{STO}}$, $\boxed{-}$, $\boxed{5}$ were stored on line seven, the display would show $\boxed{07\ 23\ 41\ 05}$. In a RUN mode, when the $\boxed{\text{SST}}$ key is pressed the location and key stroke code of the upcoming operation is displayed and when the button is released this one line of program memory is executed. The resulting contents of the X-register is now displayed. The top of memory marker (line number 00) is represented by $\boxed{00\qquad\qquad}$. To correct an erroneous command stored in program memory, switch to

PRGM mode and use either SST or BST to position the program pointer so that the erroreous command is displayed. Press BST, then enter the correct command. Since each keystroke stored in program memory is fixed to a given line number, corrections are made by directly overwriting the erroneous command with the new command.

For example, if one desired to change a R/S command stored at LINE No. 07 to a g NOP command, the following sequence should be used: RUN mode, GTO, 0, 6, PRGM mode, g, NOP (note that the display now shows 07 15 74), RUN mode.

The key g NOP means simply "do not perform any operations, pass on to the next instruction". A multiple decimal point display indicates that only one minute of operation time remains in the battery pack. The keys x⇌y, and R↓ are used to manipulate the contents of the four register stack. CLX is used to clear the contents of the X-register, f STK to clear the contents of all four registers and f REG to clear the contents of all eight storage registers. When f PRGM is pressed in a PRGM mode it clears all stored keystrokes. When used in a RUN mode, f PRGM returns the program pointer to the top of memory (LINE No. 00).

The obvious advantage to using a programmable calculator is that for a large number of data sets we need only program the calculator once. We then enter each data set and push a button to display the corresponding answer (or whatever sequence of operations the User/Instruction section specifies), reloading only those values that change from set to set. One major disadvantage of the HP-25 is that it is not card programmable, thus each program must be entered by hand, introducing the possibility of including an error in the program memory. For this reason it is suggested that the following procedure be followed before using the programs in this manual on real data:

I. PRGM mode: Clear program memory (f, PRGM) then enter those keystrokes shown in the program listing.

II. PRGM mode: Using the SST button, review the program and check the displayed keystroke code numbers against those code numbers shown in the program listing. Correct errors as necessary by directly overwriting any erroneous commands.

III. RUN mode: Enter the data shown in the **Example** section and follow the steps listed in the user instructions section. Verify that user instructions are correctly understood by comparing the calculated output to those correct answers given in the **Example** section.

A second major disadvantage of a manually programmed calculator, compared to a card programmable calculator, is that it is seldom worth the effort to reenter the program when only a few sets of data are to be used. With a card programmable calculator, once the program has been loaded onto the Program Card, we need only enter the card into the calculator to load the program. Thus we can benefit from the programmable capability of the machine when only a single set of data is to be used.

THE HP-25C has the distinct advantage that the programs stored in memory, as well as the contents of both the four-register stack and the eight storage registers are retained when the OFF/ON switch is moved to the OFF position. A similar advantage can be obtained by using an AC adapter and simply not turning the power off. If one wishes to move this calculator from one location to another, simply unplug the adapter from the AC power outlet and carry the calculator with you (the calculator operates off of battery power) then reinsert the power plug into a live power outlet at the new location.

APPENDIX B

UNIT CONVERSION TABLE

English to Metric

1 in = 25.40 mm = 2.540 cm
1 ft = 0.3048 m
1 ft^3 = 0.02832 m^3 = 28.32 liters
1 lb = 453.6 gm
1 grain = 0.06480 gm
1 lb/ft^3 = 1.602×10^4 gm/m^3
1 gr/ft^3 = 2.288 gm/m^3

Metric to English

1 cm = 0.3937 in.
1 m = 3.281 ft
1 m^3 = 35.31 ft^3
1 gm = 0.002205 lb
1 gm = 15.43 grains
1 gm/m^3 = 6.243×10^{-5} lb/ft^3
1 gm/m^3 = 0.4370 gr/ft^3

Others

1 m^3 = 10^3 liters = 10^6 cm^3
1 μm = 10^{-6} m = 10^4 Å
1 lb = 7,000 grains
1 in. Hg = 13.6 in. H_2O
R = 0.08205 liter-atm/mole–K
1 gm/gm-mole = 1 lb/lb-mole = 1 amu
°R = °F + 460
°K = °C + 273.2
°C = (5/9) (°F – 32)
°F = (9/5) °C + 32
1 ft/sec = 0.6818 miles/hr

Engineering Standard or Normal conditions are 20.0°C, 760 Torr, (68°F, 29.92 in. Hg) on a dry basis.

$$V_{(21.1^\circ C)} = 1.0038\, V_{(20.0^\circ C)}$$

$$V_{(20.0^\circ C)} = 0.9962\, V_{(21.1^\circ C)}$$